THE SCIENTIFIC CLASS-BOOK;

OR,

A FAMILIAR INTRODUCTION TO THE PRINCIPLES OF PHYSICAL SCIENCE,

FOR THE USE OF SCHOOLS AND ACADEMIES,
ON THE BASIS OF MR. J. M. MOFFAT.

PART I.

COMPRISING

MECHANICS,	PYRONOMICS,
HYDROSTATICS,	OPTICS,
HYDRAULICS,	ELECTRICITY,
PNEUMATICS,	GALVANISM
ACOUSTICS,	MAGNETISM.

WITH EMENDATIONS, NOTES, QUESTIONS FOR EXAMINATION, LISTS OF WORKS FOR REFERENCE, SOME ADDITIONAL ILLUSTRATIONS, AND AN INDEX.

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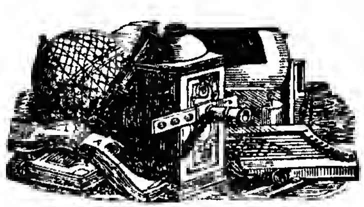

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PREFACE.

The extensive adoption in the United States of that system of education which regards *useful knowledge* as indispensable to a *useful life*, necessarily calls for the preparation of treatises adapted to the requisitions of those who are to *impart* as well as to the wants of those who are to receive such knowledge. Not only are elementary works demanded, but they must occasionally be remodelled with a view to the advancement of the sciences to which they relate. To adhere pertinaciously to the text books of the last century would be to do equal injustice to the state of education and to the progress of human knowledge. To suppose that the labours of the learned have, within the last *quarter* of a century, resulted in no modifications of elementary laws, as enunciated at the *beginning* of that period, would be to contradict the plainest evidence of daily observation. The physical sciences have, within this period, enjoyed a most vigorous growth. Not content with the bare discovery of a law and the enunciation of it as among the maxims hereafter to be received as *truth*, the views of men of science have become habitually directed to the harmonizing of the known and received laws, into more general and comprehensive expressions of nature's vast designs. By this course of proceeding, the mind is not only enabled to embrace wider ranges of thought, and more rational speculative views in *each department* or branch of science, but in several instances to include under one department the facts and phenomena previously regarded as constituting several distinct sciences. Thus while the inductive labours of Galvani and Volta laid the foundation, as *they* (and as all the world) supposed, for a *new science*, the recent researches of philosophers have wellnigh

resolved not only *that*, but two or three other sciences into one general principle of action, variously manifested according to the circumstances of each particular case. While this process of enlarging and clearing the views of men in regard to general truths in science has been advancing, there has been a constant and zealous vigilance displayed in reference to the practical applications of knowledge to the great physical and social purposes of man. These purposes can be fully subserved only by keeping the public mind apprized of all the important steps taken in the advancement of those sciences which are susceptible of a practical application. Natural Philosophy, Chemistry, and several branches of Natural History, are, of all departments of human knowledge, those which have most engaged the attention of modern philosophers; and it is with a view to the present state and the useful employment of these sciences, that the publishers of the Scientific Class Book have sought to furnish the schools and academies, no less than the private students of the United States, with an appropriate and eligible manual.

In selecting for the basis of such a manual the text of Mr. Moffatt, it was with the full understanding that in order to be adapted to the purposes of instruction here it must be somewhat varied from its English dress. Some inaccuracies in the statement of facts and principles were easily perceived; some grave errors in regard to persons, places, and things, especially in this country, were at once discovered, a number of important discoveries and inventions due to the citizens of the United States were wholly overlooked; several long notes in Latin not likely to interest the young reader had been introduced; the allusions to local objects and occurrences which pervaded the work seemed to require more oral explanation than the student in any other place than *London* was likely to receive; the puerile cuts which headed the chapters in the English editions, and which have conveyed to many persons the idea that the compilation was intended for very young children, were conceived to be less useful

than some additional figures illustrating the topics treated in the work. In the above-mentioned particulars, the work was thought to require *emendation.*

But as the several treatises appeared *in the main* to have been compiled with a view to the best authorities, as well as in a style sufficiently simple and perspicuous to warrant an attempt to adapt it to the purposes here intended, the publishers were induced to believe that they could not offer to teachers and students a more acceptable addition to the means of instruction than the work now presented for their consideration.

The general practice of introducing into class-books questions for examination is so well established as to need little comment. Yet not every kind of questions can render a text-book more valuable than it would be without them. It has been the aim of the editor so to execute this part of his duty, as to lead the student into habits of reflection on the true nature and bearings of the subject before him, not to confine his attention while answering the queries merely to certain words of the text ;—to excite the industry of the pupil, rather than increase the labour of the teacher ;—to enable the student to rise from his task with clearer conceptions of things, than he enjoyed before attempting to answer these questions, not to deceive either himself, his teacher, or others, by a show of knowledge which he does not possess. In some cases hints and suggestions are conveyed by the same means, and the application of certain terms not contained in the body of the work, will be easily understood from the manner in which they are introduced into the questions. The answers will occasionally be inferences and deductions, generally easy to be made, from the facts and principles contained in the text. In these cases the mind will, it is conceived, find a more pleasing and profitable exercise than in the mere repetition of statements found on the page to which these questions refer.

At the end of every important division of the subject is presented a list of such works as may be found useful to those who desire to prosecute particular

inquiries relating to the part immediately preceding. A few works in foreign languages are included in the number, and as the French language in particular is now so extensively *read* at least among teachers, it is believed that references to them will by no means prove useless. The index will, it is hoped, prove entirely adequate to the purpose which it is designed to subserve.

In conclusion it may be observed that, whatever merit may be claimed for other treatises on the same departments of science, it is confidently anticipated that this will be found to embrace as full and satisfactory a view of the subject which it proposes to treat, as any similar compilation, which has hitherto been dedicated to the service of American youth. In this hope the publishers respectfully submit it to the consideration of the reader.

CONTENTS.

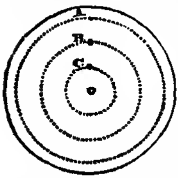
PYRONOMICS.

OPTICS.

ELECTRICITY.

to be pushed from A to B, every particle of the ball must have partaken of the motion; but if it be made to spin round in one place, the centre of the ball will remain unmoved; for imagine such a ball, or a large globular bead to be pierced centrically, and have a wire passed through it, the ball might be made to revolve with any degree of velocity, while the wire was held perfectly steady.

215. Let a circular disk of paper or any thin substance be made to revolve in this manner, on a pin, it will be perceived that the exterior surface of such a miniature wheel must move with greater velocity than any other part; so that the point A will pass over more space in each revolution of the wheel than the point B; and the latter over more than the interior point C. Hence it must follow that every circle within the circumference of a revolving wheel will have a relative velocity corresponding with its diameter; so that the degree of velocity communicated by a wheel in motion to some other part of a compound machine must depend not merely on the actual velocity of the wheel, but on that taken in conjunction with the relative distance from its centre at which the communication takes place; whether it be by means of teeth, projecting pins, or cords running in grooved cavities.



216. When teeth are made the medium for the communication of impulse, their peculiar form requires attention; but it can here only be generally stated that the teeth should be so constructed as to act upon each other steadily, without jerking or rubbing, which would soon derange the machine; and that the teeth most accurately adapted to produce the required effect, are such as have their corresponding surfaces forming peculiar curves, the exact figure of which in any case may be ascertained by geometrical construction.*

217. It is likewise desirable that the teeth of one wheel should work successively in those of the corresponding wheel, and that the same teeth should not meet in each consecutive revolution of the larger wheel; as they will thus act more uniformly, and wear away more slowly than if the same teeth came in contact more frequently. This object is effected by making the numbers of the teeth of wheels acting together, or of a wheel and its pinion,

How may this difference be illustrated in the motions of a billiard-ball?

By what will the velocity of motion of every circle in a revolving wheel be determined?

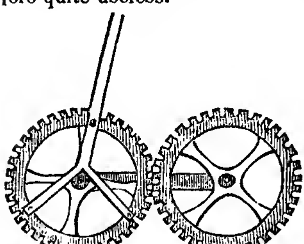
On what two circumstances in a *driving* wheel will the degree of velocity in the *driven* machinery depend?

What circumstance requires particular attention in the construction of toothed wheels?

* See Leslie's Elements of Nat. Philosophy, vol. i. p. 199—207.

as discordant as possible; so that the number of the teeth in the small wheel may never be an aliquot part of the number in the larger wheel. Thus, if a wheel of sixty teeth be turned by a pinion having but ten, each of the latter would come in contact with the same teeth of the former in each of its revolutions, or in every sixth revolution of the pinion; but if the larger wheel have sixty-one teeth, it must be manifest that no two corresponding teeth of the wheel and pinion respectively can meet more than once in every sixty-one revolutions of the pinion, during which the wheel will have revolved ten times. The odd tooth or cog by which this effect is produced is called by millwrights the hunting-cog.

218. In the construction of complex machines, it is not merely requisite that they should afford the means of communication between the power and the resistance, and enable the former to overcome the latter by the combined assistance of two or more of the mechanic powers, or simple machines; but it also often becomes an object of the highest importance to change the direction of any given moving power or acting force, without which it may be utterly inapplicable to the intended purpose, and therefore quite useless.



219. Reciprocating rectilinear motion may be changed into circular motion, by a crank applied to turn a wheel, as may be seen in the common knife-grinding machine, and in the turning-lathe; and the same effect is produced by what has been fancifully styled the sun and planet wheel, represented in the margin; one wheel fixed at the extremity of a vertical rod which rises and falls alternately, acting by teeth on its periphery on a similar wheel to which it communicates a double velocity; and thus the fly-wheel of a steam-engine was formerly made to revolve, but this method is now generally superseded by the crank.

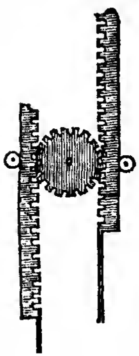
220. The opposite effect of curvilinear motion producing alternate rectilinear motion may be observed in the manner of working the pistons of an air-pump, or a fire-engine, as in the marginal figure below. A very ingenious contrivance for the conversion of rectilinear into curvilinear motion, or rather for producing an accurate correspondence between such motions, is displayed in the

How is the irregularity of wear, from the frequent meeting of the same teeth in a wheel and pinion to be avoided? What is meant by a "*hunting cog?*"

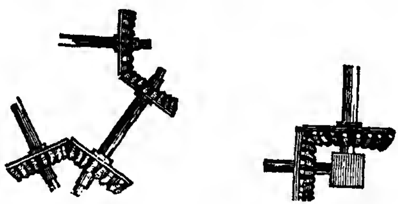
How may reciprocating rectilinear motion be changed into circular motion?

How is curvilinear converted into rectilinear reciprocating motion?

system of jointed bars used to connect the piston-rods of the steam-engine and its air-pump with the great beam, whose reciprocating motion transmits the necessary force to the fly-wheel and other parts of the machine. A much clearer idea of ths nature of this contrivance, termed the parallel motion, may be attained from inspecting a steam-engine at work, than from a detailed description, even with the aid of a figure representing its construction.



221. The universal joint, invented by the celebrated Dr. Robert Hooke, affords a simple and efficient mode of transferring rotatory motion from one axis to another in an angular direction; but this may be done with greater accuracy by means of beveled wheels, which, as will be understood



from the foregoing figures may be made to act on each other at any angle whatsoever.

222. The regulation of the velocity or rate of motion is of the highest consequence to insure the efficiency of compound machinery. When two or more of the mechanic powers are made to act in concert, they must necessarily have certain points of contact; and the material substances of which machines are constructed, being subject to variations of density and dimensions from the action of heat and cold, or other causes, regularity of action cannot be perfectly attained, unless some mode can be adopted to prevent the changes just mentioned from taking place, or to counteract their effects; so that there may be such a stability in the points of contact of the mechanic powers, as to produce uniformity of combined action. Thus, in a clock or timepiece, uniform motion is propagated throughout trains of wheel-work, by means of a pendulum oscillating seconds; and the pendulum therefore acts the part of a regulator to the clock.

223. In describing the pendulum and its peculiar kind of motion, it has been stated that to beat seconds it must have a certain

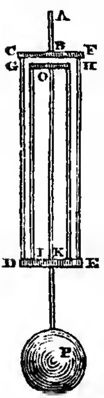
What was the purpose of Watt's jointed bars, used in the construction of his steam-engines?

For what purpose are beveled wheels applied in the construction of machines?

To what great purpose are regulators applied in the movements of machinery?

length, corresponding to the latitude of the place of observation, or more strictly speaking to the distance of that place from the earth's centre. Now it has been discovered from observation that a pendulum-rod of brass, steel, or in fact of any substance adapted for such a use, will be elongated by heat, and contracted by cold; and that to such an extent by the common changes of temperature in the atmosphere at different periods, that a pendulum which would vibrate once in a second in the winter, would take up more than a second in performing one vibration in the summer; and hence it would require to be shortened at the latter period, and lengthened again at the former to make it act with any tolerable degree of uniformity. To regulate a clock in this manner it is obvious that the error must be observed before it could be corrected, and therefore this method though it might serve for common purposes, would be nearly useless to the astronomer or the navigator, requiring a uniform and accurate measurement of a considerable period of time, by means of an instrument more or less exposed to alternations of temperature. The construction of a pendulum which should preserve its length unalterably in all situations, thus became an object highly interesting both to philosophers and mechanics; and the contrivances which different individuals have adopted or proposed have been numerous and diversified.

224. The general principle on which compensation pendulums, as they are termed, act, may be comprehended from the annexed figure and description.



Suppose C D E F to represent a steel frame, and G H a bar of metal connected by the copper rods G I and H K with the bar D E, to which they are firmly fixed. The rod O P being fastened by a pin to the bar G H, descends from it through an aperture in the bar D E, hanging freely from the point O, and supporting the pendulum-bob P: the pendulum turning on the suspension-spring A B. Now when the longitudinal rods are dilated by heat, the elongation of the rods G I and H K, will tend to raise the bar G H to which the rod O P is attached; but the corresponding elongation of the latter will tend to lower the point P; and if the apparatus be properly arranged the lengthening of one set of rods will compensate that of the other, as they must take place in opposite directions. On similar principles are constructed Harrison's gridiron pendulum and the numerous subsequent inventions, the common object of which has been to obtain a pendulum-rod, the point of contact

What character in the pendulum is indispensable in order to make it beat seconds?

By what circumstances is it prevented from acting in its simple form as a perfect regulator?

At what season of the year would a clock with a simple pendulum move most rapidly?

or axis of suspension of which shall be at a certain and invariable distance from the centre of oscillation.

225. Thus it has been shown how the effect of a single cause of irregularity of action in machinery may be obviated; but in the greater number of the complex machines employed for various purposes connected with arts and manufactures, there are often several different circumstances contributing more or less to prevent regular or uniform action. Besides the difficulty of maintaining certain points of contact between the moving parts of machines, owing to inequality of temperature and consequent contraction and expansion of solid bodies, there are additional difficuities arising from the gradual wearing away of surfaces by friction and from other causes.

226. But admitting the possibility of preserving the points of contact of the parts of a machine invariable for a certain period, abundant causes of irregular action might still exist; among which may be mentioned, as one of the most important, the irregular effect of the moving power. A familiar example of such a case will occur in the common handmill, used by grocers to grind coffee or cocoa; for a greater degree of strength must be exerted to turn the winch or handle of such a mill at the lowest point of the circle which it forms, in turning, than at the highest point; and thus the machine could not be made to act with an equable motion, but for the heavy fly-wheel, connected with the axis of the mill, which equalizes the effect, and enables the man to turn the mill with any required velocity, working without interruption or extraordinary efforts.

227. The variable inciting forces are, by the intervention of a heavy wheel, blended together in creating one great momentum, which afterwards maintains a nearly uniform action. The use of the fly in mechanics hence resembles that of a reservoir, which collects the intermitting currents, and sends forth a regular stream.* That distinguished philosopher has given a description of a machine called the concentrator of force, by means of which an inconsiderable power, acting on a fly-wheel, may be made to produce a vast momentary effect. On this principle of the effect of the concentration of force depends the action of the coining-press used for striking pieces of money. The momentum communicated to the machine by a man whirling round for a few seconds the balls at the extremities of a horizontal bar, will cause

How does the compound pendulum obviate the irregularity of a clock's movement?

What other difficulties besides those already enumerated interfere with the action of machines?

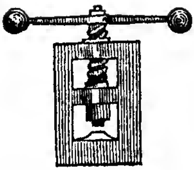
What is one of the most important sources of irregularity in a machine?

What familiar illustration of this irregularity?

By what means can force be concentrated?

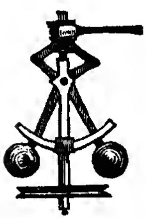
How is the coining-press enabled to produce its intense pressure?

* Leslie's Elements of Natural Philosophy, vol. i. p. 177.



the screw to descend with such force, carrying the die against a circular disk of metal, as to give it the required impression at one stroke. This machine is said to have been invented by Nicholas Briot, mint-master (*tailleur-general des monnoies*) to Louis XIII. of France ; and by using it one man may do as much work as twenty, striking coins with a hammer, which was the old method of coining *

228. A complicated machine, such as the steam-engine, requires various modifications or adaptations of its essential parts, and the addition of some peculiar parts to equalize or compensate irregular movements, and enable the engine to work with due accuracy and effect. Besides the fly-wheel, which is a necessary appendage to the common low-pressure steam-engine, there is another very ingenious and important contrivance, called the governor. It



consists of two heavy balls, connected by jointed rods with a revolving axis, by any increase in the velocity of which they diverge or separate from each other, and draw downwards the jointed rods; while a slower motion of the axis causes the balls to approach each other, and the system of rods to be contracted laterally and be extended upward. The grand effect produced by this means depends on making the ascending and descending extremity of the jointed rods raise or lower the end of a bar which acts as a lever, and moves a valve which regulates the supply of steam from the principal steam-pipe. A similar method of controlling the effect of moving power is applicable to wind and water mills, and other kinds of machinery.

229. Whatever may be the complexity of a machine, or however varied its action, its effect, theoretically considered, is to be estimated according to the principles already laid down relative to simple machines. There must be in every case an equality of effective action in the power and the resistance in order to produce equilibrium; and consequently the efficient force of the power must, with the assistance of the machine, exceed that of the weight or resistance, before motion can take place.

230. It may be generally stated that a power can counterbalance any given resistance, when the momentum of the former is rendered equal to that of the latter. This has been repeatedly demonstrat-

In what manner was the process of coining performed before the period of Briot's invention?
On what principle of motion is the mill governor constructed?
How is the effect of a compound machine to be estimated?
When will motion succeed to a state of rest in any given machine?

* V. Sigaud de la Fond Elemens de Physique, 1787, t. ii. p. 124.

ed in treating of the several simple machines. Thus, it has been shown that a lever can be kept in equilibrium only when the number of pounds in the power, multiplied by the number of feet it would describe, if put in motion, gives a product exactly equal to that of the number of pounds in the resistance multiplied by the number of feet in the space relatively described by it; so that the spaces passed through by the power and the resistance must always be in the inverse ratio of their respective weights, or actual independent forces. Hence it follows that whatever advantage is afforded by a machine, so as to enable a small weight or other weak power to overcome a great weight or resistance, must depend on communicating to the power a degree of velocity, or causing it to act through a space which shall more than equalize the momentums of the antagonist forces.

231. It may perhaps be remarked that machines, regarded in this point of view, give no additional force; since in order to raise a weight of 500 pounds, a power must be made to act with an effect superior to 500 pounds, either weight or pressure. The object of machinery certainly is not to create force, which is impossible, but to accumulate, distribute and apply it, so as to produce certain effects; and the advantage thus afforded is often of the highest importance. Thus, a man, with a crow-bar, may be able to turn over a log of wood, or a block of stone, which unassisted he could no more move than he could one of the Egyptian pyramids. But to raise such a mass of wood, or stone with a crow-bar or lever, he must make the end of the bar to which he applies his strength move through a space, probably fifty or sixty times as great as that through which he would move the log or block. So likewise if a man, who could pull with a force only equal to 50 pounds, wanted to raise a bale of goods weighing 500 pounds through the space of 12 feet, he might do it by means of a tackle of pulleys, but if it afforded him the assistance precisely necessary to supply his deficiency of strength, it must be so constructed that he would have to pull down 120 feet of rope, in order to make the bale ascend 12 feet. These examples will probably suffice to illustrate the nature of the equilibrium of action resulting from the application of machinery; and hence it will be apparent that whatever be the moving power employed for any purpose, though its actual force cannot be increased by any machine, as such an increase would involve physical impossibility, yet its effective force may often be indefinitely augmented; that is, its actual force may be made by a machine to overcome an actual resistance, to which, alone, it would be utterly inadequate.

In what proportion to the power and resistance must be the spaces which they respectively describe at the commencement of motion?

On what must the advantage of a machine for overcoming a great resistance always depend?

What is the true object of machinery in regard to mechanical force?

How may this be illustrated in the raising of a weight by the aid of a lever?

232. The action of machinery necessarily requires time to produce any given effect. Motion can in no case be instantaneous, however rapid; and when it is the result of the operation of complicated machinery, it must be relatively slow. It may indeed be the real object of a piece of mechanism to extend a series of consecutive movements through a certain period; and of such an arrangement examples may be found in common clocks and watches. In an eight-day clock, for instance, a couple of weights are wound up to a certain height, and left suspended to act by their own gravity in setting in motion trains of wheel-work which shall cause the indexes, or hour and minute hands, to describe given circles in certain spaces of time, so as to furnish a method for the equal measurement of time; and the gravitating powers of the weights are so opposed by the resistance distributed over the numerous wheels and pinions, that though the weights may each amount to several pounds, they may descend so slowly as to be more than a week in passing through the space of five or six feet.

233. A story is told by an ancient writer, relative to the celebrated Archimedes, from which may be drawn a most pointed illustration of the immensity of time and space required to produce mechanical effect, where the disproportion between the power and the resistance is extremely great. In relating the history of the siege of Syracuse by the Romans, Plutarch, in his Life of Marcellus, the Roman general, says that Archimedes told Hiero, king of Syracuse, whose confidence he possessed, as being related to that prince and highly esteemed by him, that by his mechanic skill, he could, if there was another earth for him to stand on, move the solid globe which we inhabit. Hiero, astonished at this assertion, requested the philosopher to afford him some demonstrative evidence of its truth, by letting him behold a very large body moved by a small force; and the historian adds, this effect was exhibited by Archimedes, who sitting on the sea-shore drew into port, with one hand, a large ship heavily laden, and having a number of men on board. This he is stated to have done by gently moving the handle of a machine called polyspaston, a pulley.

234. It has been remarked, that if Archimedes had proposed to move the earth by means of a lever, and had obtained not only the place he required to stand on, but also another whereon to fix his fulcrum, with an hypothetical lever of requisite length and strength, and had also been endowed with muscular power sufficient to enable him to act on the end of his lever so as to move it with the

With what are the action and effect of machinery necessarily connected?

How are mechanical forces made capable of supplying a measure of time?

How is the importance of time to mechanical actions exemplified in the celebrated assertion of Archimedes?

How did that philosopher illustrate the truth of his statement?

velocity of a cannon-ball, he would not have shifted the earth more than the twenty-seven millionth of an inch in a million of years; and supposing him to have had but the average power of a strong man, it would have taken him 3,653,745,176,803 centuries to have moved the earth with the machine he had in view in his address to his royal relative.*

235. Paradoxical as these statements may appear, it may be easily shown that they are founded on mathematical evidence. To comprehend this it will be only necessary to consider how far into boundless space such a theoretical lever as that imagined for Archimedes must have extended, and the consequent incomprehensible immensity of the arc which such an imaginary lever must be supposed to describe.

236. Those who have leisure and inclination for making such computations may ascertain what length of theoretical rope must be drawn over imaginary pulleys, to raise through the space of one inch, by means of a power equal to seventy-two pounds, a spherical mass 8000 miles in diameter, having a mean density five times that of water, and taking the weight of a cubic foot of that fluid to be 1000 ounces avoirdupois. The result of such a calculation would afford an approximation to a fair estimate of the fancied task of Archimedes; and would strikingly evince the utter insignificance of human skill and science when contrasted with the powers of nature.

Observations on Friction; on the Rigidity of Cordage; and on the Strength of Materials.

237. In making calculations or estimates of the effective force of moving powers applied to machinery, it is always necessary to admit certain deductions on account of the obstacles to freedom of motion arising from friction, the rigidity of cordage, or the imperfections of the materials of which machines must be constructed. All these subjects are of the highest importance to practical mechanicians, and are therefore deserving of the most accurate attention; but it will be sufficient here to describe briefly the nature of these obstructing or retarding forces, and to notice the methods usually adopted for lessening or correcting the inconveniences they may produce.

How rapidly might the theoretical lever of Archimedes have enabled him to move the earth?

What are the elements of calculation to show the practical result of such an attempt?

In what light would the computation place human skill and artificial powers?

On what accounts are deductions from the theoretical effects of machines rendered necessary?

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* Recreations in Mathematics and Natural Philosophy, edited by Dr. Charles Hutton, vol. ii. p. 19.

238. It is the well-known consequence of friction that when one substance moves in contact with another, either at rest or moving in an opposite direction, more or less force must be applied to produce motion in proportion to the roughness or smoothness of the surfaces of the two bodies. No substance can be perfectly smooth: not even polished steel or glass. Those surfaces that to the naked eye seem free from the slightest inequalities are found, when examined by a powerful microscope, to be covered with innumerable rising points and hollows, like the face of a file; and sometimes to be intersected by abundance of irregular ridges and furrows. Now when surfaces, such as have been just described, are made to move in contact, the prominent parts of the one will pass into the depressions of the other, and thus occasion more or less difficulty in procuring lateral motion.

239. Though friction, from its effect in retarding motion, lessens the advantage derived from machinery, and often causes inconvenience, yet it is one of those properties of matter which we find to be of almost indispensable utility. If all bodies were destitute of friction it would be very difficult for us to grasp or retain in our hands any solid substance; a penknife, a ruler, or a book would slip through our fingers, if not held tightly; and in using our hands for any purpose, such a degree of muscular power must be exerted as would be extremely fatiguing and inconvenient. But without friction it would be still more difficult to use our feet than our hands; and no man could walk upright unless he possessed the skill and activity of a tight-rope dancer, or a performer on the slack-wire.

240. The consequence of losing the advantage derived from friction in walking, may be easily conceived, when we reflect on what takes place when friction is partially destroyed by the streets and open pavements being covered with ice, as occasionally happens during the winter season. Arming the soles of the shoes with list, or with projecting nails, and covering the ice with sawdust, ashes, or other loose substances, are among the usual methods resorted to at such times, to restore friction, and enable people to walk steadily.

241. Friction is likewise advantageously used as a means of sharpening or polishing various substances, by rubbing, grinding, and other operations of great importance in several arts and manufactures. This property of matter may even be applied to the production of motion; at least it may be made the medium of communication between one part of a machine and another. Thus

To what is the resistance from friction always proportioned?
What is the true nature of surfaces commonly considered *smooth?*
By what means is the true character of surfaces to be detected?
What is supposed to be the real mode of action by which friction opposes, retards, or destroys motion?
Of what advantage is friction in the ordinary purposes of life?
How is its importance in walking made apparent?
How is friction employed in manufacturing processes?

wheels are sometimes covered on their peripheries with huff-leather, and one of them being set in motion will then turn the other, by the friction of the rough surfaces of the leather, acting as if the wheels had been furnished with innumerable series of minute teeth.

242. Such are the benefits of friction, but in many cases it proves a very inconvenient property of matter, hindering freedom of motion, and tending to obstruct it entirely; and hence in the construction of machinery various contrivances are adopted to lessen or destroy the effect of friction. Systematic writers have distinguished this property of matter into two kinds: namely, 1. That which takes place when two flat surfaces are moved in contact, so that the same points of one surface are constantly applied to some part of the other; and 2. The friction that takes place when one body rolls over another, so that the points of contact of both surfaces are perpetually changing. The former may be styled dragging friction, and the latter rolling friction.* It must be obvious that the retarding effect of the former must be vastly greater than that of the latter kind of friction. It is for this reason that plumbers, masons, and carpenters, when they want to move a heavy mass of metal, stone, or wood, place beneath it several cylinders of hard wood, by means of which such a mass may be dragged forward without coming in contact with the ground, and the immense friction of the first kind or dragging friction which must otherwise occur, is changed into rolling friction or rolling motion. On the other hand rolling friction is converted into dragging friction, by shoeing or locking the wheel of a carriage in going down a steep hill.

243. On the principle just stated depends the utility of those parts of some complex machines, called friction-wheels. In wheel-work the chief friction takes place between a wheel and the axle on which it turns; and to diminish its effect it is usual to

How may it serve as a means of communicating motion?
Into how many kinds has friction been divided by systematic writers?
Which of these exists in the mechanical devices for moving heavy masses?
What kind of friction exists at the axle, and what at the periphery of a carriage-wheel?
How is the friction of the axis of carriage-wheels diminished by means of rollers?

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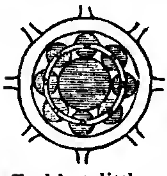
* The terms *rolling* and *dragging* friction seem more appropriate than *interrupted* and *continued* friction; as expressive of the mode of action by which they are respectively produced. A true case of rolling friction takes place only when the rollers are so situated as to have no necessity of employing axles; as when cylinders or cannon-balls are placed beneath heavy weights. The wheel-carriage is not a case of this kind, for it only transfers the friction which would take place at the periphery if the wheel were locked to the axle, which experiences a dragging friction within the box.—See on this subject Journal of the Franklin Institute, vol. 5, p. 57.—Ed.

construct the axle and the box, or central part of the wheel, of very hard substances, the surfaces of which are not only rendered as smooth as possible, but also covered with oil, or some other unctuous matter, which facilitates the motion of the corresponding parts. But where it is necessary to obtain the utmost facility of motion, a method has been adopted for subdividing friction, by letting the axle of a principal wheel move on two or more small wheels, as in the marginal figure. These are named friction-wheels.*



244. In estimating the effect of friction, so many circumstances must be taken into the account, that the result, in any given case, may afford but little assistance in deciding others. It may however be stated, as the most important deduction from repeated experiments, that friction does not depend on the extent of the surfaces on which it acts, but chiefly on the degree of pressure to which they are subjected; so that, the surfaces continuing in the same state, increase of pressure will produce increase of friction.

245. When a heavy body is placed on an inclined plane, it will have a tendency to slide; and consequently will remain at rest on such a plane, only when the retarding effect of friction is greater than the tendency for motion, caused by the inclination of the plane. Hence the angle of inclination at which motion on an inclined plane commences, has been styled the *angle of friction*; and it will of course be different in different cases, according to the nature of the rubbing surfaces, and the degree of pressure.

246. The rigidity of cordage is another property of solid bodies which interferes with the freedom of motion in some kinds of machinery. It must necessarily depend on the peculiar nature of the materials used, since the more flexible they are, the more readily will they become adapted to the wheels or spindles around which they are coiled; and the smaller will be the interruption of regular continued motion. It is principally when very thick lines are used, such as the cables for heaving anchors for very large ships, that this rigidity of cordage becomes a serious impediment to motion, requiring the expenditure of great force to overcome it. Iron chains have been advantageously introduced into the maritime service, instead of cables; and are likewise employ-

What is one of the most important deductions from experiments on friction?
What is meant by the *angle of friction?*
Is this angle constant or variable?
To what does the rigidity of cordage usually offer its resistance?
What substitutes for large cables have of late been adopted?

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* The railroad cars of Winans, Howard, and several others, employing friction-wheels, have been invented in the United States, and will be found described in the early volumes of the Journal of the Franklin Institute.—ED.

ed for various purposes in the arts to which ropes alone were formerly considered applicable.

247. In the construction of machines much must depend on the strength and firmness of the materials of which they may be composed. Thus, in the caso of one of the most simple macbines, the lever, suppose a long pole to be applied to raise a considerable weight, much of the effect of any power would be lost in consequence of the bending of such a wooden lever at that part which rested on the fulcrum; and therefore an iron bar, noarly inflexible, of the same length with the pole, would enable a man to move any given weight or resistance with less exertion.

248. The hardness, tenacity, elasticity, and other properties of bodies, on which their relative strength must principally depend, vary so greatly even in different specimens of the same substance, as wood or metal, that few rules of general application can be given for computing the degrees of force, which may be applied with safety to the particular parts of any complex machine. Any solid substance, as a bar or rod of iron, may be subjected to tension or pressure in different ways: as, (1), by suspending to it a great weight, or endeavouring to stretch it longitudinally; (2), by weight or pressure applied to crush or compress it; and (3), by weight or pressure applied to the centre of a bar or rod, its extremities alone being supported.

249. It appears from experiment, that in the first case, the length of a rod remaining the same, its strength will be increased or diminished in proportion to the area of its transverse section; thus, as 27 tons weight will tear asunder an iron bar one inch square, so a bar but half a square inch in the section will be broken by a weight of 13½ tons; and so on in any given proportion. Concerning the capacity of bodies for resisting compression, but little is known with certainty. Much appears to depend on the form of a body, for a cubie inch of English oak required to crush it a weight of 3860 pounds; but a bar an inch square and five inches high gave way under the weigbt of 2572 pounds; and if longer it would manifestly have broken with a less weight. Mr. Rennie, one of the architects of London Bridge infers from calculation that the granite of which the great arch of that bridge is constructed would bear a pressure equal to four tons upon every square inch of its upper surface.

250. As to the strength of bodios exposed to transverse or lateral pressure, one or both ends being supportod, it depends on the dimensions of a section of the body in the direction of the pres-

On what circumstances must the usefulness of machines chiefly depend?

Name some of the physical properties of materials which vary their usefulness in the mechanic arts.

In how many ways may a solid rod of any material be subjected to mechanical actinn?

How is direct *tension* applied? how *crushing pressure?* how *cross strain?*

What inference has been drawn by Rennie from experiments on granite?

sure. Thus a beam having the same length and breadth with another, but twice its depth, will be four times as strong; and a beam double the length of another, but with the same breadth and depth, will have but half as much strength. Hence the strength of solid bodies is not by any means to be estimated by their absolute magnitude.

251. Hollow cylinders are much stronger than solid ones of equal length and weight; and therefore it appears an admirable provision of nature that the bones of men and other animals in those parts requiring facility and power of motion are more or less of a cylindrical shape, with cavities in the centre, which in birds, are filled only with air, whence partly their capacity for flight; but in men and beasts the cavities are filled with a light oily fluid, which congeals after death, forming marrow. The strength or efficient power of an animal depends chiefly on the accurate construction and adaptation of its several parts.

252. Some very small creatures possess muscular power, in proportion to their bulk, incomparably greater than that of the largest and strongest of the brute creation. A flea, considered relatively to its size, is far stronger than an elephant or a lion; as will appear from comparing the distance the insect would leap at one bound with its actual dimensions, with reference to the spring and dimensions of the quadruped. Some marine animals, as the whale, are of vast bulk; nature having provided for their convenience by giving them a medium of great density to inhabit.

Moving Powers.

253. The original forces which produce motion, and which have been denominated Moving Powers, or Mechanical Agents, are of various kinds, depending on the natural properties of bodies. Gravitation or weight is an extensively acting power affecting matter in all its different forms, and affording the means of originating motion for many useful and important purposes. By the proper application of weight is excited and maintained the equable motion of wheel-work, as in a common clock; and the same power differently adapted is made to act by percussion, in pile-driving and numerous other operations. Currents of water owe their velocity to the weight of the descending liquid, yielding a kind of moving power on which depends the effective force of water-wheels and other hydraulic engines.

254. Elasticity is another property of matter which gives ener-

What relation exists between the dimensions of a beam and the resistance which it is capable of opposing to cross strain?

What advantage does the hollowness in the bones afford to the strength of animals?

How are we to judge of the relative strength of insects and of large animals?

What is one of the most common mechanical forces, and in what different modes is its efficacy applied?

gy to various mechanical agents. Elastic metals, as steel, manufactured into springs, are used in the construction of watches or chronometers; and the contractile force of springs is employed for many other purposes, as in roasting-jacks and weighing-machines. Liquids, though compressed with difficulty, display a high degree of power when thus treated; and machines of vast energy have been invented, the effect of which depends on the expansive or elastic force of compressed water. The elasticity of air is likewise an abundant source of moving power. Steam-engines, such as were used in the early part of the last century, were mado to act through atmospheric pressure, arising from the joint influence of the weight and elasticity of the air; but since the vast improvements in machines of this description, in consequence of the researches of Watt, and other experimental philosophers, steam or elastic vapour is employed as the sole moving power, and so managed as to produce effects far beyond those of the old atmospheric engines.

255. Heat must be regarded as a moving power, the efficacy of which depends on its tendency to dilate different kinds of matter. It also converts solid bodies to the liquid state, and liquids under its influence are changed into vapours or gases. Hence indeed is to be explained the operation of the steam-engine, in which alternating motion is produced by the expansive force of steam or water raised to the state of vapour by means of heat. Combustion is a chemical process, often excited by heat, and during the progress of which heat is always developed; and from this source is derived moving power of vast intensity, as occurs in the discharge of shot or balls from fire-arms, through the explosion of gunpowder. In this case the moving power arises from the sudden expansion of gases formed by the combustion of solid matter; but engines have recently been constructed the action of which depends on the formation of a partial vacuum by the inflammation of oxygen and hydrogen gases in close vessels, and the consequent production of water.

256. Machines may be set in motion by means of electricity, galvanism, or magnetism; and forces, which have been chiefly regarded as objects of curiosity may be extensively applied to useful and important purposes. In a French periodical publication (Journal de Geneve, 1831), some account is given of an electrical clock, inventod by M. Bianchi of Verona. This timekeeper has neither weight nor spring, instead of which the constant vibra-

State some of the applications of elasticity to purposes connected with the arts?

What is the difference in principle between the atmospheric engine of Newcomen and the modern steam-engines of Watt and Evans?

On what is the efficacy of heat as a moving power dependent?

In what other modes is heat occasionally applied to produce mechanic ction?

What other imponderable agent, besides heat, is occasionally employd as a moving force?

tion of the pendulum is maintained by the impulse of electricity, which it receives by moving between two galvanic piles, the ball or or bob being furnished with a conductor, which in its oscillations, approaching either pile, alternately, is repelled by the discharge of the electric fluid; and the regular action of the whole of the machinery is kept up.

257. These cursory observations will afford some general ideas of the nature and extent of the moving powers originating from the influenee of elastic fluids, heat, and electricity; but the further discussion of these topics must be referred to the subsequent portion of this work, where the phenomena connected with these subjects will be distinctly noticed. There are, however, besides those moving powers, the operation of which depends on the physical properties of matter in different states of aggregation, other mechanical agents, the effects of which arise from the vital energy of animated beings; and concerning these some details may here be properly introduced.

258. The application of the natural strength of man must have preceded the employment of all other moving powers; and we know from history, that ever since a very remote period brute animals have likewise been rendered subservient to the purposes of art and industry. The employment of oxen and horses in the labours of the field must have originated in the earliest ages; and the art of training beasts of different kinds to exert their strength for the benefit of man has been known and practised among almost all nations except those in the very rudest state of society.

259. The mechanical effects produced by the muscular exertions of living beings cannot be subjected to calculation on precisely the same principles as the moving power of a weighing-machine or a steam-engine; nor even can they be estimated with so much precision as the efficient power of a windmill or a water-wheel; but there are modes of obtaining data whence to determine the value of animal strength as a mechanical agent, which may serve to indicate the comparative product of labour from that and other sources, and enable us to discover their relative importance for any given purpose.

260. The usual method of computing the mechanical value or efficiency of labour is from the weight it is capable of elevating to a certain height in a given time, the product of these three measures (weight, space, and time) denoting the absolute quantity of performance. But these measures have obviously a mutual relation which will affect the result; for great speed will occasion a

Describe Bianchi's galvanic clock.

On what do the effects of animal efforts depend when employed for mechanical purposes?

What were among the earliest *zoolic* moving forces employed in the arts?

Can the power of animals be accurately computed by their weight and velocity?

What three elements enter into the computation of animal power?

waste of force, and shorten the period during which it can be exerted. It was computed by Daniel Bernoulli and Desaguliers that a man could raise two millions of pounds avoirdupois one foot in a day. But some writers have calculated that a labourer will lift ten pounds to a height of ten feet every second, and continue to work at that rate during ten hours in a day, raising in that time 3,600,000 lbs. But these estimates are certainly incorrect, and appear to have been founded on inferences drawn from momentary exertions under favourable circumstances. Smeaton states that six good labourers would raise 21,141 cubic feet of sea-water to the height of four feet in four hours; so that they would raise about 540,000 pounds each to the height of ten feet in twenty-four hours.

261. Coulomb has furnished some of the most exact and varied observations on the measure of human labour. A man will climb a staircase from 70 to 100 feet high, at the rate of 45 feet in a minute; and hence, reckoning the man's weight at 155 pounds, the animal exertion for one minute would be 6975, and would amount to 4,185,900, if continued for ten hours. But such exercise would be too violent to be thus continued. A person might ascend a rock 500 feet high by a ladder-stair in twenty minutes, or at the rate of 25 feet a minute: his efforts are thus already impaired, and the performance reduced to only 3875 in a minute.

262. But with the incumbrance of a load the quantity of action must be yet more remarkably diminished. A porter weighing 140 pounds, who could climb a staircase forty feet high two hundred and sixty-six times in a day, was able to carry up only sixty-six loads of fire-wood, each weighing 163 pounds. In the former case, his daily performance was very nearly 1,489,600; while in the latter it amounted to only 799,920. The quantity of permanent effect in the latter case* therefore was only about 800,000, or little more than half the labour exerted in mere climbing. A man, drawing water from a well by means of a double bucket, may raise 36 pounds one hundred and twenty times a day, from a depth of 120 feet, the total effect being 518,400. A skilful labourer working in the field with a large hoe produced an effect equal to 728,000. When the agency of a winch is employed in turning a machine, the performance is still greater, amounting to 845,000.

263. The effective force of human exertion differs according to the manner in which it is applied. From some experiments made by Mr. Robertson Buchanan, it was ascertained that the labour of a man employed in working a pump, turning a winch, ringing

What are the suppositions adopted by Bernoulli and Desaguliers in regard to the amount of human effort?

To what results did Coulomb arrive in respect to the speed of human movements, and to the continued daily labour of men when working only to raise their own weight, and when carrying up additional burdens?

According to what circumstances does the effective force of human exertion vary?

* The *useful* effect in the former case was 0; in the latter it was 430,320.

a bell, and rowing a boat, might be represented respectively by the numbers 100, 167, 227, and 248. Hence it appears that the act of rowing is an advantageous method of applying human strength.

264. A London porter is accustomed to carry a burden of two hundred pounds at the rate of three miles an hour; and a couple of Irish chairmen will walk four miles an hour, with a load of 300 pounds. But these exertions are by no means equivalent to those of the sinewy porters in Turkey, the Levant, and other parts bordering on the Mediterranean. At Constantinople, an Albanian will carry 800 or 900 pounds on his back, stooping forward, and assisting his steps by a short staff. At Marseilles, four porters commonly carry the immense load of nearly two tons, by means of soft hods passing over their heads, and resting on their shoulders, with the ends of the poles from which the goods are suspended.

265. The most extraordinary instances of muscular exertion in the carriage of burdens are those exhibited by the cargueros or carriers, a class of men in the mountainous parts of Peru, who are employed in carrying travellers. Humboldt, in relating the circumstances of his descent on the western side of the Cordillera of the Andes, gives some account of the cargueros. It is as usual in that country for people to talk of going a journey on a man's back, as it is in other countries to speak of going on horse back. No humiliating idea is attached to the occupation of a man-carrier, and those who engage in it are not Indians, but Mulattoes, and sometimes whites. The usual load of a carguero is from 160 to 180 pounds weight, and those who are very strong will carry as much as 210 pounds. Notwithstanding the enormous fatigue to which these men are exposed, carrying such loads for eight or nine hours a day, over a mountainous country, though their backs are often as raw as those of beasts of burden, though travellers have sometimes the cruelty to leave them in the forests when they fall sick, and though their scanty earnings during a journey of fifteen or even thirty days is not more than from 11 to 12 dollars, yet the employment of a carguero is eagerly embraced by all the robust young men who live at the foot of the mountains.*

266. The different races of mankind display much diversity of muscular strength; though in all cases much must depend on the constitution and habits of the individual. M. Peron † has stated the results of some interesting experiments which he made to

In what kind of exertion did Buchanan find the greatest, and in what the least advantageous employment of the strength of men?

What striking examples can you enumerate of the transportation of heavy loads?

Who are the cargueros, and what feats of strength are related of them by Humboldt?

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* See Humboldt's Researches concerning the ancient inhabitants of America; with Descriptions of the most striking Scenes in the Cordilleras. London, 1814.

† Voyage de Decouvertes aux Terres Australes, fait par ordre du gouvernment pendant les annees 1800—4.

discover the relative mechanical power of individuals of different nations. For that purpose he used an instrument called a Dynamometer, which, by the application of spiral springs, to a graduated scale, afforded the means of estimating the forces exerted by the persons who were the subjects of his experiments. He collected by this method a number of facts, which he conceived sufficient to enable him to deduce from them the medium forces or powers of exertion of the inhabitants of the Island of Timor, of New Holland, and Van Diemen's Land, and to compare them with those of the English and the French. The following is the order of arrangement, commencing with the weakest: Manual force—Van Diemen's Land, N. Holland, Timor, French, English. The proportion between the two extremes is nearly as 5 to 7. Lumbo-dorsal force, [*force des reins*]—the order the same as before; but the proportion between the extremes, as 5 to 8.

267. The labour of a horse in a day is usually reckoned equal to that of five men; but then the horse works only eight hours, while a man can easily continue his exertions for ten. Horses display greater power in carrying than in drawing; yet an active walker will beat them in a long journey. Their effective force in traction seldom exceeds 144 pounds, but they are able to carry six times that weight.* The pack-horses in the West Riding of Yorkshire, England, are accustomed to convey loads of 420 pounds over a hilly country; and in many parts of that country the mill-horses will carry the burden of even 910 pounds, for a short distance.

268. The most advantageous load for a horse must be that with which his speed will be greatest in proportion to the weight carried. Thus, if the greatest speed at which a horse can travel unloaded be 15 miles an hour, and the greatest weight he could sustain without moving be supposed to be divided into 225 parts, then his labour will be most effective when, loaded with 100 of those parts, he travels at the rate of five miles an hour. The common estimate of horse-power adopted in calculating the effect of steam-engines is wholly hypothetical. It is stated by Watt to be that which will raise a weight of 33,000 pounds the height of one foot in a minute of time, equal to raising about 90 pounds four miles an hour. Another estimate reduces the weight to 22,000 pounds raised one foot in a minute, equivalent to 100 pounds $2\frac{1}{2}$ miles an hour. This mode of calculation seems to have been introduced as a matter of convenience, when the use of horses in mills and factories was superseded by that of steam-engines; and must have been adopted in order to show the superiority of steam-

To what extent did Peron discover that different nations vary in the forces which they can exert in different modes of exertion?

In what manner do horses exert their strength to greatest advantage?

What is generally found to be their effective force of traction?

What will be found the most advantageous load for a horse?

What is the estimate of horse-power assigned by Watt in calculating the effect of steam-engines?

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* It does not follow that it is better to use *pack-horses* than wagons.—ED.

engines over horses according to the most exaggerated statement of the power of the latter.

269. The ass, though far inferior to the horse in strength, is yet a most serviceable beast of burden to the poor, as he is easily maintained at little cost. It has been found that in England, an ass will carry about 220 pounds twenty miles a day; but in warmer climates, where he becomes a larger and finer animal, he may be made to trot or amble briskly with a load of 150 pounds.

270. Dogs are now frequently used for draught in various countries. The Kamtschatdales, Esquimaux, and some other northern people, employ teams of dogs to draw sledges over the frozen surface of snow. They are harnessed in a line, sometimes to the number of eight or ten, and they perform their work with speed, steadiness, and perseverance. Captain Lyon, when he visited the Arctic regions, had nine of these dogs, who dragged 1610 pounds a mile in nine minutes, and worked in this manner during seven or eight hours in a day. Such dogs will draw a heavy sledge to a considerable distance, at the rate of 13 or 14 miles an hour; and they will travel long journeys at half that rate, each of them pulling the weight of 130 pounds.*

271. The elephant was used by the Romans for the purposes of war, as it is still in India, and other oriental countries. His strength is reckoned equivalent to that of six horses, but the quantity of food he consumes is much greater in proportion. An elephant will carry a load of 3000 or 4000 pounds; his ordinary pace is equal to that of a slow-trotting horse; he travels easily 40 or 50 miles a day; and has been known to go 110 miles in that time.

272. The camel is a most valuable beast of burden on the sandy plains on both sides of the Red Sea; for traversing which, the animal might seem to have been expressly created. Some camels are able to carry 10 or 12 hundredweight; others not more than 6 or 7; and with such loads they will walk at the rate of 2½ miles an hour, and travel regularly about 30 miles a day, for many days together, being able to subsist eight or nine days without water, and with a very scanty supply of the coarsest provender.

273. The dromedary is a smaller species of camel, chiefly used for riding, being capable of travelling with greater speed than the larger camel, but not equally proof against exhaustion. The best Arabian camel or dromedary, after three whole days' abstinence

For what purposes have dogs often been employed?
At what speed, and with what loads, can the Arctic dogs travel?
At what speed, and with what load, can the elephant travel?
What circumstances of its constitution adapt the camel for usefulness in the particular climate where it is found to subsist?
For what particular labour is the dromedary adapted?

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* The exhibition called the Hall of Industry, shows the force of dogs applying their strength on a *flexible inclined plane.*—Ed.

from water, shows manifest symptoms of great distress; though it might possibly be able to travel five days without drinking; which, however, can seldom or never be required, as it appears that, in the different routes across the desert of Arabia, there are wells not more at the utmost than 3½ days' journey from each other. Exaggerated statements have been given of the speed of this animal; the most extraordinary performance of which the traveller Burkhardt ever obtained authentic information having been a journey of 115 miles in eleven hours, including two passages across the Nile in a ferry-boat, requiring twenty minutes each. The same traveller conjectured that the animal might have travelled 200 miles in twenty-four hours. A Bedouin Arab has been known to ride express from Cairo to Mecca, 750 miles, upon a dromedary, in five days. Twelve miles an hour is the utmost trotting-pace of the smaller camel; and though it may gallop 9 miles in half an hour, it cannot continue for a longer time that unnatural pace. It ambles easily at the rate of 5½ miles an hour; and if fed properly every evening, or even once in two days, it will continue to travel at that rate five or six days.

274. The lama, or guanaco, is a kind of dwarf camel, which is a native of Peru; and it was the only beast of burden employed by the ancient inhabitants of that country. It is easily tamed, feeds on moss, and being admirably adapted for traversing its usual haunts, the lofty Andes, it is still employed to carry goods. The strongest of these animals will travel, with a load of from 150 to 200 pounds, about fifteen miles a day over the roughest mountains. There is a smaller animal of a similar nature, called the Pacos, which is also now used by the Peruvians in transporting merchandise over the mountains; but which will carry only from 50 to 70 pounds.

275. Oxen have been, in many countries, employed in the labours of husbandry, instead of horses. They are, however, inferior, not only on account of the softness of their hoofs, which renders them, if unshod, unfit for any except field work, but likewise as being comparatively unprofitable. A team of oxen capable of ploughing as much land as a pair of horses will require for support the produce of one-fourth more land, after allowing for the increase of weight and value.

276. In some parts of Europe the goat is made to labour, by treading a wheel to raise ore or water from a mine. They are, in England, sometimes harnessed to miniature carriages for children; and in Holland the children of the rich burghers are thus drawn by goats, gaily caparisoned, and yoked to light chariots. The

What is the greatest speed of the camel?
At what constant rate can it usually travel?
What is the load and speed of the lama of South America?
Why are oxen inferior to horses in the labours of husbandry?
In what manner has the goat been employed as a mechanical agent?
In what region, and for what purpose, is the rein-deer made subservient to the purposes of man?

rein-deer of Lapland is a most serviceable beast of draught in the frozen regions of the north. Two of these deer, harnessed to a sledge for one person, will run 50 or 60 miles on the stretch; and they have been known to travel thus 112 miles in the course of a day.

At what speed can this animal travel?

The foregoing statements and illustrations will, in general, be found sufficient for the class of students for whose use this work is chiefly designed. For the use of teachers and others who may desire to pursue the subject more into detail, and to find rigorous demonstrations of the principles above laid down, we would make the following references to works which may with more or less facility be obtained by the American reader.

Cambridge Mechanics, by Prof. Farrar, p. 13—278.
Fischer's Elements of Natural Philosophy, p. 10—52.
Playfair's Outlines of Natural Philosophy, p. 19—168.
Boucharlat, translated from the French by Professor Courtney
Gregory's Mechanics.
Library of Useful Knowledge, article *Mechanics*, three numbers.
Robinson's Mechanics, edited by Dr. Brewster, in 4 vols.
Young's Mechanics.
Lagrange Mécanique Analytique.
Biot Traité de Physique.
Journal of the Franklin Institute, *passim*.

Many more works might be named, but the above it is believed will constitute a sufficient collection of subsidiary works to aid the teacher in his private investigations under the different heads embraced in the preceding treatise.—Ed.

HYDROSTATICS.

1. As the science of Mechanics treats of the phenomena depending on the properties of weight and mobility in solid bodies, so Hydrostatics relates to the peculiar effects of the weight and mobility of liquids. The term hydrostatics properly denotes the stability of water,* or in a more extensive acceptation, the pressure and equilibrium of liquids at rest. The effects produced by the flowing of water or any other liquid, have sometimes been regarded as appertaining to a distinct department of natural philosophy, named Hydraulics;† and occasionally the whole doctrine of mechanical science as applicable to liquids has been treated of under the designation of Hydrodynamics,‡ which, howover, seems to possess no such peculiar property as to warrant its general adoption; and therefore the term Hydrostatics may be retained as denoting the science whose object is to explain the phenomena arising from the influence of gravitation on water and other liquids whether in the state of rest or in that of motion.

2. Liquids differ in some of their distinguishing properties from solids, and in others from gases or aërial fluids; forming an intermediate class of bodies. A solid, by the disintegration of its parts, may be reduced to a state bearing some resemblance to that of a liquid, thus fine sand or any light powder will yield to pressure in every direction, almost as readily as water; but the resemblance is still extremely imperfect. Viscous fluids, as train oil or treacle, approach to the nature of solids; and indeed the distinction between such liquid substances and some of the softer solids, as butter or honey, depends much on their relation to heat, their consistence or relative density varying with the temperature to which they are exposed.

3. As the effect of temperature on different bodies will constitute the subject of a separate treatise, it will be sufficient at present to state that the peculiar degrees of density and tenacity of unorganized substances, constituting the respective states of solidity and fluidity, with their various modifications, seem to be chiefly influenced by heat and pressure; so that a particular substance, as water, may exist under different forms, depending on the circumstances in which it is placed. Thus a certain degree of cold will convert water into a hard solid, as ice or hail, which, when melted by heat, produces a liquid differing in no respect from the water of which it was formed; and this when exposed

To what is the term hydrostatics properly applied?
To what is *hydraulics* sometimes appropriated?
What other term has been used to denote the mechanical properties and effects of liquids?
In what manner may solid substances be made to resemble liquids?
What class of liquids bear an analogy to solid bodies? What circumstances influence the density and tenacity of unorganized substances?

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* From Υδωρ, water, and στασις, standing. † From Υδωρ, and αυλος, a pipe. ‡ From Υδωρ, and δυναμις, power.

to a sufficiently high temperature, will evaporate or become steam, which may be again condensed or restored to the liquid state by cold. Mercury commonly occurs in the form of a very dense liquid; but it may, like water, be condensed or frozen by exposure to an extremely low temperature, and be made to boil or evaporate by subjecting it to a great degree of heat. The other metals differ from mercury only in remaining solid in higher temperatures than that substance; but they all melt with various degrees of heat, and become sublimed or evaporated when the heat is greatly raised above the melting point.

4. Since the same kind of matter may exist under different states or forms, it follows that liquids must be composed of the same particles as solids, and the difference between a liquid and a solid may be conceived to arise, merely, from peculiar modifications of the cohesive attraction which takes place between the constituent molecules or particles of such bodies respectively. The particles of elastic solids must be capable of a sort of vibratory motion, from sudden pressure, but they will always resume the same position as soon as the vibration ceases, unless it be so violent as to occasion a permanent separation of the particles, when the solid becomes broken or pulverised. Now liquids have their constituent particles, held together like those of solids, by cohesive attraction, but they oscillate on the application of the slightest impulse; and there seems to be such a general relation of all the particles to each other, that when the connexion between any two particles is broken, by shaking or otherwise agitating the mass of which they form a portion, they readily become attracted by any other particles with which they may happen to come in contact, new cohesions take place, and when the disturbing force is removed, the general equilibrium is restored throughout the liquid mass.

5. The cohesive attraction between the particles of liquids is demonstrated by the globular figure which they assume, when no external force interferes with the aggregation of the mass. This appears in the case of mercury thrown in small portions on a china plate, or on any surface which exercises on it no chemical attraction; when the minute portions into which it will become separated, will be found to be perfect spherules, the larger ones only being slightly flattened by the pressure occasioned by their own weight on the plate. Similar spherules, consisting of drops of water,

Through what successive changes of state may bodies occasionally pass? Give some examples of these changes?

Whence arises the difference between a liquid and a solid body?

Of what action are the particles of elastic solids necessarily susceptible?

By what force are the particles of liquids held together?

What constitutes the difference between breaking a solid and separating the parts of a liquid?

How is the cohesive attraction between the particles of a liquid demonstrated?

are formed by dew or rain on the broad leaves of some kinds of vegetables, as those of the common cole-wort or cabbage. If, however, the drops become large, as when two or three run together, they spread out at the edges, sinking down, and becoming flattened, partly through their own weight, and partly owing to the attraction between the water and the surface of the leaf.

6. The general appearance or figure which liquids assume when at rest is the joint effect of the extreme mobility of their constituent particles, of the gravitation of liquid masses, and of their attraction for the solids on which they are sustained. Hence when a liquid in any considerable quantity is poured into a vessel of any shape whatever, it adapts itself exactly to the internal surface of the vessel, the superior or unconfined surface of the liquid forming a horizontal plane, usually raised a little at the sides or border of the vessel, where the liquid is attracted by the containing solid with which it comes in contact.

7. When an immense mass of liquid presents a continued surface, its form will be a portion of a convex sphere; because the collective gravitation of all its particles towards the centre of the earth causes it to partake of the general figure of the terrestrial globe. This, indeed, will be the case with comparatively small bodies of liquid; but when it is considered that the radius of the sphere, of which any such liquid surface formed a part, would be equal to half the diameter of the earth, it must be manifest that the difference between the surface of a small portion of such a sphere and a horizontal plane would be too inconsiderable to be distinguished. Vast collections of water, however, as the open sea, afford decisive indications of superficial curvature, among the most striking of which is the fact that when a vessel first comes in sight its masthead alone is visible, and the lower parts appear successively as it approaches the observer, rising as it were out of the bosom of the deep.

8. Among the properties in which liquids differ most remarkably from gases, is the power of sustaining pressure to a considerable extent, without undergoing any obvious change of volume. Common air, steam, and other elastic fluids, as they are termed, may be compressed by very moderate force, and on its removal they expand to their original dimensions, as may be ascertained by squeezing a blown bladder; but a leather bag or strong bladder filled with water, and secured so that none of the liquid can escape, may be burst by forcible compression, but cannot be made to exhibit any sensible degree of contraction. Such indeed is the

On what three circumstances does the figure assumed by a liquid at rest depend?
What is the external form of a large mass of liquid?
Why is this form taken rather than any other?
What sensible evidence is afforded of the spherical form of the earth?
In what respect do liquids differ essentially from gases?
How was water formerly regarded in respect to compressibility?
On what experiment was this opinion founded?

extraordinary resistance of water, when subjected to pressure on all sides, that it was long regarded as absolutely incompressible. This opinion was partly founded on an experiment made in the sixteenth century, by the members of a scientific society at Florence, called Academia del Cimento. These philosophers conceived the idea of enclosing a quantity of water in a hollow globe of beaten gold, and exposing it to the powerful action of a screw press, when it was found that the water was forced through the pores of the gold ball or case, standing in drops like dew on its exterior surface. But this experiment, can by no means be considered as demonstrating the entire incompressibility of the liquid; for though it obviously displayed vast resistance to the compressing force, it might have undergone the utmost limit of condensation before the exudation took place; and the experiment was unsatisfactory, as affording no means whatever for appreciating the actual volume of the water at the moment when it penetrated the solid envelope. In fact, nothing more could be inferred from such an experiment, but that water is not susceptible of unlimited condensation.

9. The fallacy of the formerly generally received notion of the absolute incompressibility of water was proved by some ingeniously contrived experiments by Mr. Canton, a fellow of the Royal Society of London, in 1761. He showed that water, included in a glass tube with a large bulb or hollow globe at its extremity, expanded and consequently stood higher in the tube when placed under an exhausted receiver than when subjected to the pressure of the atmosphere, and on the contrary was condensed proportionally, by pressure equal to the weight of two atmospheres. He made similar experiments on spirit of wine, olive oil, and mercury, from which it appeared that those liquids undergo condensation, but in different degrees, when subjected to compression. In conducting these experiments proper precautions were adopted to prevent any inaccuracy arising from variation of temperature; and the following table exhibits the results obtained when the barometer stood at 29½ inches and the thermometer at 50 degrees.

10. Spirit of wine underwent compression amounting to

	0.000,066 of its bulk.
Olive oil, - - -	0.000,048
Rain water, - -	0.000,046
Sea water, - - -	0.000,040
Mercury, - - -	0.000,003

Hence it appears that mercury is far less compressible than water.

What legitimate inference can be drawn from the Florentine experiment?

By whom was the fallacy of the opinion formerly entertained respecting the compressibility of water first demonstrated?

State the manner in which Canton's experiments were conducted?

What other liquids besides water were proved by Canton to be compressible?

11. More recently, experiments on this interesting subject have been instituted by M. Oersted, a philosopher who has greatly distinguished himself by his scientific researches; and the results of his investigations, which appear to have been very carefully conducted, correspond nearly with those of Canton, the contraction of water, under pressure equal to the weight of an additional atmosphere, according to the experiments of Oersted, amounting to 0.000,045.

12. Experiments have been undertaken in England with a view to ascertain the effect produced by subjecting liquids to compressing forces of vast energy, far beyond those employed in the researches of Canton and Oersted. In 1820, an account was laid before the Royal Society of London by Mr. Jacob Perkins, of some experiments from which he inferred that water had suffered a compression of about one per cent. of its bulk by a pressure equal to 100 atmospheres; and in other experiments the compressing force was augmented to 326 atmospheres, which caused a contraction of the liquid to the amount of nearly 3½ per cent. These results were obtained by including water in the cavity of a cannon, fixed vertically in the earth, and driving more water into it with a forcing pump; and corresponding experiments were made by sinking water inclosed in a proper apparatus to a great depth beneath the surface of the sea, and observing the degree of compression it had undergone.* These operations, however, could not be regarded as equally accurate with those previously described; though the deductions from them have been corroborated by the result of subsequent investigation.

13. In 1826 Mr. Perkins made public other experiments on the compression of water, of which also an account appeared in the Philosophical Transactions. The machine he employed was composed of a cylinder of gun-metal, 34 inches in length, and having an internal cavity to which was adapted a steel pump, with a water-tight piston, by means of which water could be injected into the body of the cylinder. A lever apparatus was properly annexed for the purpose of measuring the degree of pressure; and so adjusted that the number of pounds pressing on its piston indicated exactly the number of atmospheres equivalent to the degree of compression.

14. That part of the apparatus in which the liquid is enclosed, the condensation of which is to be measured, is called by the experimentalist a piezometer.† It consists of a strong glass tube, eight inches in length and half an inch in diameter, closed at one

To what results has Oersted been led by his experiments on water?
How many atmospheres of pressure are required to condense water to the amount of one per cent. of its ordinary bulk?

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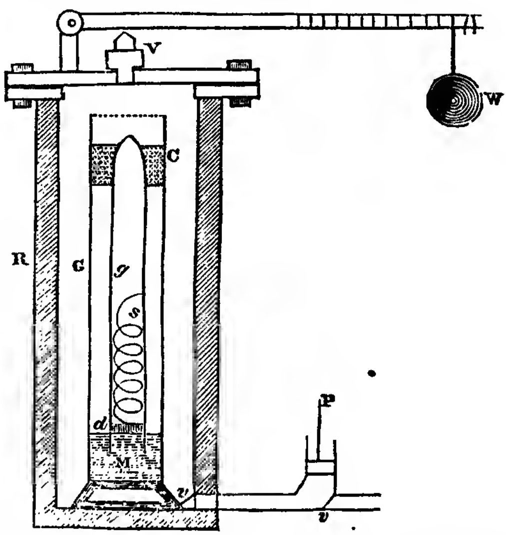
* See Philosophical Transactions, 1820, and Abstract of Papers in Philosophical Transactions, vol. ii. p. 134.
† From the Greek Πιέζω, to press, and Μέτρον, a measure.

extremity and open at the other. This tube must be carefully filled with water freed from air, and being inverted while the water is prevented from escaping by the application of a thin membrane to its mouth, it must be inserted in a wider tube or glass, the upper part of which is filled with water, and the lower part with mercury; the small tube contains a hair-spring pressing against its interior surface so as to retain its position when forced upward; and this spring is in contact with a steel disk moving freely in the upper tube, and from its inferior weight supported by the surface of the mercury below. A frame of strong wire retains the small tube in its situation; and the piezometer being thus arranged is introduced into the receiver of the compressor, filled with water at a temperature of 50 degrees, when the pump being screwed into its place, any required degree of pressure may be applied. When the experiment was carefully conducted it was found that water, under the influence of a force equal to 2000 atmospheres, was diminished by 1-12 part, as indicated by the situation of the spring.*

15. The nature of Mr. Perkins's mode of compressing water, will



By what part of its original bulk under atmospheric pressure will a force of 2000 atmospheres, or 30,000 lbs. to the square inch, condense a given mass of water?

What is the construction of Perkins's piezometer?

* This curious and interesting experiment is exhibited daily, at the National Gallery of Practical Science, in the Strand, London.

perhaps be more clearly comprehended from the annexed figure, in which R is the metallic cylinder, G the wider glass tube with a quantity of mercury, M at the bottom; *g* is the piezometer dipping into the mercury below and kept steady by the wire cage C near the top; *d* is the steel disk, and *s* the hair-spring to be moved upward when the water in *g* is compressed, and the mercury with the disk *d* rises, and to remain and indicate the degree of compression after the experiment. The use of the force pump P with its two valves, *v*, *v*, and that of the safety valve V, with the lever and weight W serving to determine the force applied, will be readily understood. The apparatus of Oersted substitutes a strong glass receptacle for the metallic one of Perkins; and his piezometer is a nearly capillary tube in which a thread of mercury rises by the compression and forces before it the water with which the whole upper part of the tube, (hermetically sealed at top,) is filled. Oersted employs to compress the liquid instead of the steel pump, a strong thumb-screw inserted into the top of the brass cap with which his glass receptacle is closed. He also encloses a thermometer, not hermetically sealed, to mark the degree of heat, if any, developed by the effect of mechanical compression.

16. Though it is manifest, from the preceding statements, that liquids undergo great compression under certain circumstances, yet the degree of compressibility of such liquids, as water, is so inconsiderable when the compressing force is moderate, that no sensible effect is produced. Hence in all calculations concerning the action of water, at rest or in motion, in ordinary cases, it may be regarded as an incompressible fluid.

17. Liquids in general possess the property of elasticity; but like solids, some of them display that property to a greater extent than others. When a solid disk, as an oyster-shell or a flat stone, is made to strike the surface of water at a small angle, as in the sport which schoolboys call making ducks and drakes, the solid will rebound from the water with considerable force and frequency. So a musket-ball impinging obliquely on water will take a zigzag course, *en ricochet*, as the French express it. Water dashed against a hard surface, as when it is poured against the side of a china basin, or let fall on a plate, shows its elastic force, in flying off in drops in angular directions. Experiments on the elasticity of drops of water, spirit of wine, or any similar liquid, may be made in a shallow wooden box, having its bottom and sides thinly covered with any light insoluble powder; for the drops on being impelled against the side of the box, or even against each other, will rebound like miniature cricket balls or marbles.

Might this instrument be employed with advantage to measure the compression suffered by water in *deep-sea* experiments? Describe the arrangement of apparatus employed by Perkins in the compression of water. How may water be regarded under the influence of moderate changes of pressure? What evidence is afforded of the elasticity of water by the impinging of solid bodies upon its surface? How may we demonstrate the elasticity of drops of water?

18. Mercury is yet more elastic, as might be shown by placing a small quantity of it in a little case made by bending at right angles the sides of a common playing-card; and on inclining it so as to make the metallic fluid strike one of the raised sides of the card, the shining globules would recede with a velocity proportioned to the violence of the shock. The effects thus exhibited appear to be extremely similar to those observed in the case of elastic solids. A globule of mercury impinging on a hard surface becomes slightly flattened, but instantaneously resuming its curved figure, it recoils like a bent spring suddenly liberated. In some hydraulic operations the elasticity of liquids becomes a property of considerable importance, variously augmenting or modifying the efficient force of particular kinds of machinery.

Weight and Pressure of Liquids.

19. Among the absurd doctrines heretofore generally received, but which have been exploded by the light of modern philosophy, must be reckoned that of the non-gravitation of the particles of liquids on each other. That liquids as well as solids possess weight was never denied; since every one must have learnt from experience that a cup or a bucket filled with water would require a greater exertion of force to lift it than when the water was removed. But it was observed that in drawing water from a well, so long as the bucket remained under water very little effort was required to raise it, while as soon as it emerged from the surface of the liquid, the loaded bucket would press downward with a force proportioned to the quantity of water contained in it. This, and the general observation that heavy bodies were easily raised while under water, gave rise to the vague idea that a liquid did not gravitate in its own element, and that therefore a body surrounded by any liquid was destitute of weight.

20. The following experiment sufficiently proves that this is not the case. Let a strong phial, with a stop-cock fitted to it, be exhausted by means of an air-pump, and the stop-cock being turned let it be suspended from one arm of a balance, so that it may be entirely immersed in a vessel of water, weights being placed in the opposite scale of the balance to keep it in equilibrium; then if the stop-cock be opened the water will flow in and fill the phial, which will immediately sink, and to restore the equilibrium the same weight must be added that would counterpoise the water it contains if weighed alone: thus, if the bottle would hold exactly four ounces of water, a weight of four ounces would be required to make the balance stand even as at first.

How are analogous experiments on mercury conducted?

What appears to be the effect of the impact of a drop of mercury upon a hard surface?

What opinion was formerly entertained respecting the gravitation of liquids upon their own mass?

From what circumstance did this idea probably take its rise?

How is its incorrectness conclusively demonstrated?

21. The apparent diminution of the weight of bodies under water is owing to the particles of the liquid mass gravitating equally in every direction; so that the interior portions of any liquid, or of solids immersed in liquids, are subjected to the same degree of pressure on all sides; and therefore a body surrounded by water is partially supported by it, and consequently may be raised through the liquid with greater ease than in the air, a fluid, the relative density of which is so very inconsiderable. Liquids are not less powerfully affected by gravitative attraction than solids, but they exhibit different appearances under its influence, owing to their being constituted differently, so that their particles move freely and almost independently of each other.

22. All the constituent particles of a solid are firmly connected, and they thus act with combined effect in producing pressure or impact; but a liquid yields to force in any direction, and is liable to be separated into small masses, the effect of which is comparatively inconsiderable. A basin of water poured from a great height on a man's head would hardly be felt more than a current of rain; but if the contents of the basin, supposing it to hold a quart, were suddenly changed to a solid mass of ice, it might occasion a fracture of the skull. But though a liquid in falling becomes almost dissipated through the resistance of the atmosphere, it displays great force when it can be made to act in a continuous column. Hence the power of a mill stream in turning large wheels either by weight or pressure; and the tremendous violence of a cataract, sweeping away great stones or other ponderous masses which may present any obstruction to its impetuous course.

23. The effect of a liquid mass when its particles are protected from dispersion, and thus enabled to act in concert, like those of a solid body, may be amusingly illustrated by means of the little instrument called a water-hammer. It consists of a strong glass tube, about twelve inches long, and nine or ten lines in diameter, having three or four inches of water included in it; which being made to boil and form steam by the application of a proper heat, the tube must be hermetically sealed by means of an enameller's lamp and a blow-pipe, so that when it becomes cool, a vacuum will be formed above the water by the condensation of the inclu-

How is the apparent loss of weight in bodies immersed in water to be explained?

To what is the difference attributable between the phenomena exhibited by liquids and those observed in solids, when under the influence of gravitation?

How are the constituent parts of each held together?

What simple experiment would illustrate the influence of a change of form, in modifying the effect of water?

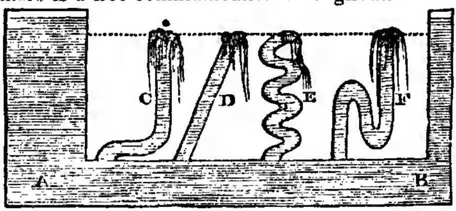
What examples may be cited of great energy displayed by a falling liquid?

By what apparatus may the percussion of a falling mass of liquid be illustrated?

Describe the water-hammer.

ded steam. On shaking such a tube vertically, the water, rising a few inches and sinking suddenly to the bottom of the tube, produces a sound like that arising from the stroke of a small hammer on a hard body, whence the name of this instrument, the action of which depends entirely on the exclusion of the air, so that the water moves in a dense mass.

24. The pressure of liquids extending equally in all directions, a liquid mass will have all parts of its surface at the same level, whatever be the form of the vessel in which it is contained, so long as there is a free communication throughout.



25. In the preceding figure let A B represent a glass vessel closed except at the two raised extremities, and filled with water to a height above the horizontal line; then suppose four differently shaped tubes C, D, E, F, open at both ends, to be inserted in the oblong part of the vessel, with their upper extremities not rising so high as those standing at the sides; it will be found that the liquid will pass laterally into the tube C, ascend directly in D, and circuitously in E, while it both descends and ascends in F, rising equally in all the tubes, and spouting out till the water is reduced in the side tubes to the level of the summits of the internal ones, when the equilibrium being established the liquid will remain at rest. Thus it follows that any number of columns of a liquid, freely communicating, whatever may be their respective diameters and figures will always have the same vertical height.

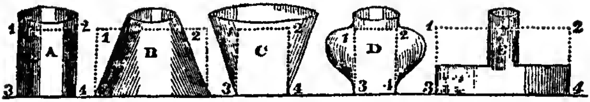
26. Yet though all the particles of a liquid mass will press equally on each other, it must be manifest that the collective weight will be proportioned to the depth beneath the surface, so that the bottom of the containing vessel necessarily sustains the weight of a column having the greatest vertical height of the liquid with an area equal to that of the base itself.

27. If the vessels A, B, C, D, and E, have water poured into them in such quantities that it may stand at the same height in each, the pressures on their bases respectively will be as the several columns marked 1, 2, 3, 4. Hence the amount of the pres-

What consequence results from the equal pressure of liquids, in regard to the height of its surface?

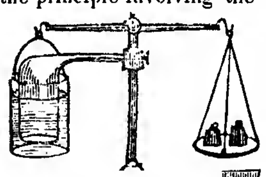
What influence has the figure and size of the parts of containing vessels on the height to which liquids will rise within them respectively?

What measures the pressure exercised by a column of liquid on the bottom of its containing vessel?



sure of any liquid may be ascertained by multiplying the vertical height at which it stands by the extent of surface of its base. Thus suppose the water in the vessel B to stand at the height of four inches, and the area of the base to be eight square inches, the pressure will be equal to thirty-two inches of the fluid; but if the water should stand at the same height in the vessel C, having a base only half the area of the former, the pressure will be but half or only sixteen inches, though the capacity of both vessels may be exactly the same. The diameter of a vertical column communicating with an extended base may be relatively inconsiderable, as in the vessel E, notwithstanding which it will cause the same degree of pressure as a column of the same height with a diameter corresponding to the base throughout.

28. This effect of the vertical pressure of liquids may be variously exhibited, and its results are curious and important. Hence the principle involving the peculiar mode of pressure of liquid masses has been termed the Hydrostatic Paradox. It may be illustrated by the following experiment. Let a cup or wide-mouthed jar, filled with water, be poised by hanging it to the arm of a balance, by loading the opposite scale with the requisite weights; then after marking exactly the height at which the liquid stands, pour out a part of it, and plunge into the midst of the jar a conical block of wood, supporting it with the hand or by means of the apparatus represented in the annexed figure, taking care that the block shall not touch the sides or bottom of the jar. If it be plunged just deep enough to raise the remaining liquid to the same height as at first, the balance will be again exactly equipoised; and the block may be so large as to leave only a thin film or hollow cylinder of the fluid without at all disturbing the equilibrium. It is of no consequence what is the weight or shape of the body introduced, for a piece of cork or a blown bladder held in the jar will produce the same effect, if its bulk be sufficient to raise the water to the required height.*



By what mode of calculation may we ascertain that pressure?

If a vessel representing the frustum of a cone be filled with liquid, and successively placed on its two opposite bases, what will be the relation between the pressures exercised in the two cases?

What is meant by the *hydrostatic paradox?*

What experiment exemplifies the kind of pressure exercised by liquids?

How can we prove that the loss of weight from plunging a body into water is only apparent?

* An ingenious apparatus for drawing water from a vessel in which a

29. There is another striking mode of illustrating the effect of liquid pressure, by means of a kind of machine called the Hydrostatic Bellows, a figure of which may be seen in the margin. It

is composed of two flat boards united at the sides by flexible leather, and having a long narrow vertical tube, communicating with the cavity, with a funnel at the top, for the convenience of pouring in water or any other fluid; and a short lateral tube with a stop-cock may be added to discharge the water occasionally. If now water be poured into the long tube it will fill the cavity and consequently separate the boards, and by adding more water the instrument may be made to support any given weight, in proportion to the height of the vertical column. Suppose the boards to be about 320 inches superficial measure, four ounces of water, standing at the height of three feet in the tube, will keep the boards separated when loaded with 416 pounds.

30. Two stout men standing on the upper board, one of them by blowing into the tube may fill the cavity with air instead of water, so as to raise the board on which they stand, and by stopping the pipe with the finger to prevent the air from escaping, they may keep themselves supported.

31. The force of water pressing on an extended surface by means of a small vertical tube may be shown by fixing such a tube in a water-tight cask or other close vessel, which, whatever its strength, might be burst by filling it with liquid, and adding more through the tube, till the weight of the column became too great to be supported by the sides of the cask. The effect depends wholly on the height of the tube, its diameter being immaterial. A hogshead filled with water and exposed to the pressure of a column in a narrow tube, twenty feet high, would burst with great violence.

32. Astonishing effects are sometimes produced by the pressure of water modified in the way already described. As when a shallow body of water is collected in a close cavity under ground,

Describe the construction, and explain the principle, of the hydrostatic bellows?

In what manner might the same principle be applied to maintain a regular blast of air for the blow-pipe?

In what manner do we demonstrate the importance of height of column to the effect of liquid pressure?

In what manner may the effect of hydrostatic pressure on portions of the earth's surface be manifested?

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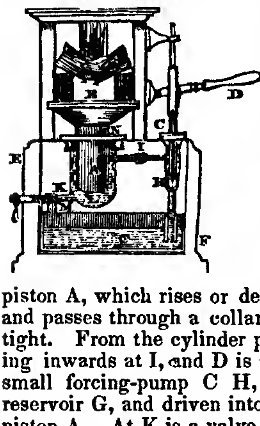
solid has been made to float until the liquid has the same level as at first, and then weighing the quantity drawn out against the solid which had been floating, proves the same general position as the arrangement above described. It moreover shows that the weight lost by the solid, and the upward pressure of the liquid which is the cause of that loss, are both equal to the weight of water so displaced.—Ed.

if a narrow opening be made from a higher surface communicating with the cavity, and it should become filled by rain or snow water, whatever might be the form of the aperture, if it was water-tight, as soon as the communication was effected between the tube-like opening and the cavity, pressure would take place in every direction, in a degree proportioned to the vertical height of the opening and the area of the cavity; in consequence of which the superincumbent mass might be rent from its foundation, and a large building or even a mountain might be overthrown, as by an earthquake.

33. The principle of hydrostatic pressure was discovered, or at least first satisfactorily demonstrated, by the celebrated Pascal, about the middle of the seventeenth century; and he showed how an engine might be constructed, acting through the force of a column of water, by means of which one man pressing on a small piston might counterbalance the efforts of one hundred men brought to bear on the surface of a large piston. Yet notwithstanding the distinct description of what the ingenious discoverer terms "a new machine for multiplying forces to any required extent,"* more than a century and a half elapsed before the idea was fully developed, and applied to practical purposes, by Mr. Bramah, the engineer, in the construction of his hydrostatic press.



34. This machine consists of a solid mass of masonry or strong woodwork, E F, firmly fixed; and connected by uprights with a cross-beam. B represents a strong table, moving vertically in grooves between the uprights, and supported beneath by the piston A, which rises or descends within the hollow cylinder L, and passes through a collar N, fitting so closely as to be water-tight. From the cylinder passes a small tube with a valve opening inwards at I, and D is a lever which works the piston of the small forcing-pump C H, by which water is drawn from the reservoir G, and driven into the cylinder L, so as to force up its piston A. At K is a valve, which being relieved from pressure, by turning the screw which confines it, a passage is opened for the water to flow from the cylinder, through the tube M, into the reservoir G, allowing the piston to descend.

35. The effective force of such a machine must be immensely

Who first demonstrated the principle of hydrostatic pressures according to the height of column?

What application did Pascal propose to make of the principle of pressure according to the area of the base of the containing vessel?

By whom, and at what period, was the idea of Pascal fully realized?

What is the construction of Bramah's press?

* Pascal de l'equilibre des liqueurs, edit. 2, 1664, ch. ii.

great, combining as it does the advantages of solid and liquid pressure. The amount of the latter is to be estimated by the relative diameters of the two pistons; so that if the piston H be half an inch in diameter and the solid cylinder or piston A one foot, the pressure of the water on the base of the piston A will be to the pressure of the piston H on the water below it, as the square of 1 foot or 12 inches, $12 \times 12 = 144$, to the square of ½ an inch, $.5 \times .5 = .25$; that is as 144 square inches, to ¼ of a square inch, or in the ratio of 576 to 1. To this must be added the advantage afforded by the lever handle of the forcing-pump, depending on the relative lengths of its arms; and supposing the power to be thus increased tenfold, the effect of the machine will be augmented in that proportion, or will become as 5760 to 1.

36. As the hydrostatic press acts with a comparatively trifling degree of friction, it may be made to produce an infinitely great amount of pressure; its efficiency in fact being limited only by the measure of the strength of materials employed in its construction. Some idea of the power of this engine may be derived from the statement that with such a press, only the size of a common tea-pot, a person may cut through a thick bar of iron with no more effort than would be required to slice off a piece of pasteboard with a pair of shears. It has been used in making experiments on the tenacity and strength of iron and steel, being applied so as to tear asunder solid rods or bars;* and in packing bales of cotton or trusses of hay, it has been employed to compress them to convenient dimensions for stowage on board ships.

37. The principle of hydrostatic pressure has been ingeniously applied to a purpose of great practical utility by Dr. Arnott, in the contrivance of a hydrostatic bed for invalids. It is so constructed as to keep the body of a person reposing on it, sustained by a mattress on a liquid surface, yielding freely in every direction, and therefore entirely exempted from any irregular pressure: thus the irksomeness, as well as the serious evils caused by confinement to one position for a long time, and the consequent injuries which persons enfeebled by disease somotimes incur, may be wholly prevented.

38. The pressure of water or any other liquid against the bottom of a vessel in which it is contained may be regarded as the common effect of gravity, which acts in the same manner on solid

What method will enable us to estimate the advantage of a Bramah's press of known dimensions?

What advantage has the hydrostatic press over the screw press and similar machines?

What limits the efficiency of this apparatus?

What remarkable applications of the hydrostatic press illustrate its force and usefulness?

What is the construction of Arnott's Invalid bed?

In what respects does the pressure of a liquid within a containing vessel differ from that of a solid under the same circumstances?

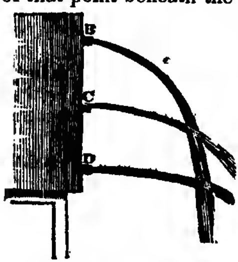
* See Encyclopedia Metropolitana—Mixed Sciences, vol. i. p. 70.

bodies; but liquids not only press on the surface beneath, but also press upward, with a degree of force proportioned to the depth of the vertical column and the extent of surface against which the pressure is exerted.

39. Take a very narrow glass tube open at both ends, and dip the lower extremity beneath the surface of quicksilver, so that a small portion of it may rise into the bottom of the tube; then stopping the upper extremity carefully with the finger, lift the tube, and holding it vertically, plunge the open end into a deep jar filled with water, when it will be found that the pressure of that liquid from below upwards will not only keep the quicksilver suspended, when the finger is removed from the top of the tube, but on letting it sink gradually in the jar, the quicksilver will rise to a height bearing a certain relation to the depth of the lower end of the tube beneath the surface of the water.

40. Let a circular brass plate A B be adapted to the bottom of a glass cylinder and fitted accurately by grinding, or by covering its upper surface with moist leather, so that when the cylinder is immersed in the jar of water F F, and the plate is held by the string E close to the bottom of the cylinder, none of the liquid can enter it. If then it be immersed to such a depth that the weight of the vertical column of water which it displaces shall be equal to the weight of the brass plate, the latter will remain suspended though the string be let go, the upward pressure of the water being sufficient to keep the plate from falling.

41. In estimating the lateral pressure of liquids the vertical height must be taken into the account; since the effective force with which a liquid acts against any given point in the side of the containing vessel will depend on the depth of that point beneath the surface of the liquid.



42. This will appear from the manner in which water flows from apertures in the side of a cistern, as the velocity of the stream will always be exactly proportioned to the distance of the point of discharge from the superior surface, and the consequent degree of pressure which takes place. Suppose a vessel A to be filled with water, and to have three tubes or pipes, B, C, D, of equal length and diameter, fitted into lateral apertures at different heights; then if

How are we to account for the rising of a drop of quicksilver in a narrow tube, when plunged into water?

To what depth must a metallic plate, ground to fit the open mouth of a glass tube, be immersed in a liquid before the upward pressure of the liquid will support the plate? What is to be taken ioto the account in estimating the lateral pressure of liquids?

the liquid were suffered to flow from the pipe D alone, the others being stopped, a greater quantity of water would be discharged in a given time than by the pipe C alone, and a greater quantity would issue from the latter in the same time than by the pipe B only; the water being kept at the same level, so as to maintain an equality of pressure during the whole time it was flowing. And if all three pipes were opened together, the water would spout to a greater distance from the pipe D than from either of the others.

42. The pressure against one side of a cubical vessel filled with liquid will be equal to half the pressure against the bottom of the vessel. Hence in a quadrangular cistern the amount of pressure against its sides may be found by multiplying the number of square feet contained in that part of the sides beneath the surface of the liquid by half the height at which it stands; and therefore if the extent of the lateral area in contact with the liquid be double that of the bottom of the containing vessel, the pressure on the sides will be equal to that on the bottom. Thus a calculation may be made of the pressure of water against a dam, wear or floodgate, by ascertaining the superficial measure of the surface against which the water presses, and multiplying it by half the depth of the vertical column. Suppose a dam to be built across a body of water 6 feet in depth and 14 feet wide, the extent of the surface subjected to pressure would be 84 square feet, which being multiplied by 3, half the depth, the product 252 would denote the quantity of cubic feet of water pressing on the dam. In the same manner may be ascertained the degree of pressure of a liquid standing in an upright cylinder, as a leaden pipe or cistern; by multiplying the number of square inches or feet in the curved surface by half the depth of the liquid: and this method may be extended to all cases of the lateral pressure of liquids, whatever be the shape of the containing vessel or cavity.

43. When a liquid presses on any surface there will be a certain point at which a degree of pressure being applied equal to the entire pressure of the liquid would produce exactly the same effect; or if such equivalent pressure were applied to that point, but in the contrary direction, it would neutralize the pressure of the liquid on the opposite surface: that point is therefore called the centre of pressure. It corresponds exactly with the centre of percussion in solids, which in most, but not all cases, coincides with the centre of oscillation. To ascertain the situation of this

To what is the distance to which liquids will spout from an aperture in a containing vessel always proportioned?

What relation exists between the velocity of flow and the height of the aperture?

How may we estimate the pressure against the side of a cubical containing vessel filled with any liquid?

To what practical purposes may this method of calculation be applied?

How is the amount of pressure on a cylindrical tube or vessel filled with liquid to be determined?

What is meant by the term *centre of pressure* in liquid masses?

With what point in solid masses does the centre of pressure correspond?

point often becomes an object of importance; since it will indicate the most efficient means for sustaining a floodgate or any similar surface against the pressure of a body of water. The position of the centre of pressure must depend on the figure of the surface and the depth of the head of water. Supposing the surface to be a perpendicular parallelogram, the centre of pressure will be at two-thirds of the distance from the level of the water to the bottom; and if the figure of the surface be an equilateral triangle, at three-fourths of the distance from the vertex to the base.

44. On the principle of the lateral pressure of liquids may be estimated the pressure sustained by solids immersed at any depth beneath a liquid surface. Thus, if it be required to find the pressure which a diver sustains when he has descended in water to the depth of 32 feet, or rather to such a depth that the centre of gravity of his body may be exactly 32 feet beneath the surface of the water; then as the extent of surface of a human body, at a medium, may be estimated at 10 square feet, the product of that number multiplied by 32 will give the quantity of water in cubic feet, the weight of which must be sustained by the diver at the depth just stated. Now as one cubic foot of water weighs 1000 ounces avoirdupois, the weight of 320 cubic feet will be 320,000 ounces or 20,000 pounds.*

45. The equability of the pressure in every direction renders such an immense weight supportable; though it occasions considerable inconvenience to persons learning to dive, from the intense pain caused by the pressure of the water on the drums of the ears, even at the depth of 18 feet below the surface. It appears probable that diving in very deep water, at length, has the effect of rupturing the membrane called the drum of the ear, after which pain in that organ is no longer felt by the diver;† but there must be a limit to the depth to which the most experienced diver can descend, since at a very great depth the compressing force of the liquid mass would be so augmented as to expel entirely the air that had been retained in the cavities of the chest and head,

On what circumstance will its position depend?

At what point in a floodgate in the form of a rectangular parallelogram might a single force on the side opposite to that pressed by the water be applied, so as to resist the whole pressure of the liquid within?

How may we find the amount of pressure upon the body of a diver, when at a given distance below the surface?

Why is not a person crushed by the weight of liquid above him, when placed many feet below the surface of water?

What peculiar sensation is felt at first by persons unaccustomed to deep diving?

What is supposed to take place when the inconvenience at first felt is found to cease?

Why may not a man descend to any depth below the surface of water?

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* The manner of ascertaining the weight of any body relatively to its bulk will be described in the next section, in treating of specific gravity.

† See Hardy's Travels in the Interior of Mexico. London, 1829.

and contract the hulk of the whole body in such a manner as to render ascent to the surface no longer practicable.

47. The uniform pressure of liquids in every direction, and the consequent equality of action and reaction among the parts of liquid masses cause them to assume a level surface under all circumstances. This property of liquids has been advantageously employed in the construction of instruments for ascertaining the relative heights of any given points, as in taking levels in surveying, and in various operations in which it is requisite to determine the accuracy of a horizontal plane. Such an instrument may consist of a glass tube of considerable length, as represented in the margin, open at both ends, which must be raised or turned upward to the same height; and the tube being filled with water or mercury, when

it is placed in a horizontal position, the liquid will stand at the same level on both sides. Upon the open surfaces of the liquid must be placed floats, each carrying upright sights with cross-wires, which standing at right angles to the length of the instrument, when it is properly adjusted, the intersections of the wires will be situated in a horizontal line; and consequently on looking through the sights at any distant object it can only be seen exactly opposite the intersections of the wires when it happens to be in the same level.

48. The spirit level, an instrument adapted to the same purposes with the preceding, consists of a glass tube, closed at both ends, and filled with alcohol, except a very small space occupied by a bubble of air, which, in whatever situation the tube may be placed, must rise to the highest part of it. When, therefore, the tube is fixed in a horizontal position, the bubble will stand precisely in the centre of the tube and in contact with its surface. Such a level may be used like the water-level, above described, for ascertaining the accuracy of a horizontal plane; or it may be mounted in a frame with moveable sights adapted to a quadrant, by means of which the angular distances of objects may be determined with the utmost degree of correctness.

49. The property which liquids possess of preserving an exact level in different tubes or vessels communicating with each other is of the highest importance, as indicating an obvious mode of conducting water from one situation to another. Thus from a lake or reservoir this useful fluid may be conveyed in pipes or tunnels underneath streets and buildings to any given distance, and supplied to the different quarters of a town or city, at any height not exceeding that of its source. The whole amount of the daily

What is the general construction of liquid levelling instruments?
What is the form and use of the spirit level?
On what principle are we enabled to conduct water under ground, and through irregular tubes?

supply of water to the cities of London and Westminster appears to be nearly 26,000,000 gallons, more than half of which is derived from the Thames; and as most of it is delivered at heights much above the level of the river, it is necessarily raised by artificial pressure by means of steam-engines.

50. Though water and similar liquids may be transferred to any imaginable distance through a series of communicating tubes bent into numerous angles, descending and ascending, and made to issue freely at a height nearly equal to the source; yet it is found in practice that obstruction, arising from the friction of the liquid against the sides of the tubes, especially where they form acute angles, and from the accumulation of bubbles of air in long narrow tubes, may cause great inconvenience; and hence large pipes are more advantageously employed than smaller ones, and aqueducts or open conduits are to be preferred in some situations.

51. In the south of Europe may be seen the remains of stupendous aqueducts constructed by the ancient Romans, forming open canals supported by numerous arches passing across wide valleys, and exhibiting even in decay striking memorials of the architectural skill and industry of those to whom they owe their origin. From these magnificent works on which such immense labour must have been bestowed for the purpose of conducting water on one descending plane, it has been hastily inferred that the ancients were entirely ignorant of the effect of hydrostatic pressure; and of the means of making water rise to the height of its source after passing through a lower level. But this notion is utterly erroneous, for in the great work of the celebrated naturalist, Pliny the elder, it is expressly stated that water will always rise to the height of its source; and he adds that tubes of lead must be used to carry water up an eminence.* Passages to the same effect might be adduced from other ancient writers, containing plain allusions or direct statements relative to the consequences of the pressure and flow of water. Indisputable evidence that the ancients were not ignorant of this principle has been afforded by the researches made among the ruins of Pompeii, where the remains of fountains and baths show that the inhabitants of that city, which was destroyed in the reign of the Emperor Titus, were not unskilled in the means of causing water to ascend through pipes and conduits. The reason why the Romans did not adopt the method of conducting water through large tubes was chiefly because they were unable to construct such tubes as would be

Of what nature are the impediments to the motion of liquids in conduit pipes?

In what manner were the ancients accustomed to conduct water from a distance into their cities?

What evidence have we that the ancient Romans understood the principles of hydrostatic pressure as applicable to subterranean conduits?

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* Plinii Hist. Natural. lib. xxxvi. cap. vii. See Leslie's Elem. of Nat. Philos. pp. 411—413.

water-tight when exposed to the pressure of a considerable column of liquid. Their water-pipes were made of lead, earthenware, or wood, and were in many respects inferior to those used in modern times.

52. Some of the most remarkable phenomena of nature are owing to the tendency of liquids to form coherent masses, to become extended over the surfaces of solids, and to flow in any direction till they find a common level. Water is the most abundant of all liquids, and if we trace its operations under the several forms of rain, springs, fountains, running streams, lakes, or rivers, communicating with the extended ocean, the peculiar properties which constitute the distinctive character of liquid bodies will be recognized in the effects which they produce. Some notice has already been taken of the different states of aggregation which water assumes when exposed to certain degrees of temperature, being expanded or converted into vapour by heat, and condensed by cold.* It may be considered as making its first appearance as a liquid in the form of falling rain, which consists of drops of water recently produced by the condensation of aqueous vapours.

53. "The drops of rain vary in their size, perhaps from one twenty-fifth to one-fourth part of an inch in diameter. In parting from the clouds, they precipitate their descent till the increasing resistance opposed by the air becomes equal to their weight, when they continue to fall with a uniform velocity. This velocity is, therefore, in a certain ratio to the diameter of the drops; hence thunder and other showers in which the drops are large pour down faster than a drizzling rain. A drop of the twenty-fifth part of an inch, in falling through the air, would, when it had arrived at its uniform velocity, only acquire a celerity of eleven feet and a half per second; while one of one-fourth of an inch would acquire a velocity of thirty-three feet and a half."†

54. Experimental inquiries have frequently been instituted as to the quantity of rain which had fallen at any particular place during a certain period. An estimate of the amount of aqueous fluid discharged from the atmosphere might be formed from observing the quantity of rain-water descending on the roof of a house or any other building, provided the whole could be collected and measured before any portion of it had been dissipated by evaporation, and an exact measurement could also be obtained of the superficial area of the surface on which the rain had fallen.

Why did not the ancients carry all their aqueducts beneath the surface of the ground?

What limits the velocity of water descending in the form of rain?

To what is the resistance of the air to falling drops of water proportioned?

How might an estimate be formed of the amount of water descending annually over the surface of a country?

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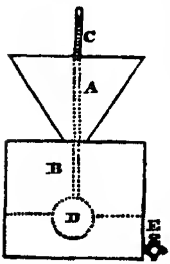
* See Mechanics, 54. † Leslie's Treatise on Heat and Moisture.

There are some situations in which this plan might be executed without much difficulty.

55. But a more generally applicable, though perhaps less satisfactory method of ascertaining the daily, weekly, monthly, or annual fall of rain, in any situation, is by means of an instrument called a pluviameter, or rain-gauge. This instrument has been variously constructed, and the different forms which have been recommended may each have their particular advantages; but the general object of all of them is the collection of rain falling on an area of known extent, as a few square inches, and providing for its accurate measurement. Below is represented a rain-guage which has at least the merit of simplicity, as showing, on inspection, the quantity of rain-water which may have fallen on a certain area during any given time. It consists of a quadrangular-topped funnel, A, the opening of which may be ten inches square, terminating below in a reservoir B. Through the neck or opening between the funnel and the reservoir is inserted the graduated rod C, to which is adjusted the ball D, made of cork or light wood, so that it may float on the surface of the water in the reservoir, and the upper part of the rod being marked with divisions into inches and parts of an inch, will indicate by its ascent the depth of water in the reservoir. The stopcock E serves to let off the water after its quantity has been noted, or at any stated periods. A more simple instrument consists of a conical vessel about 8 or 9 inches high and 5 inches in diameter, placed in a convenient frame and furnished with a rod, graduated progressively to correspond to the varying size of the cone.



56. According to the observations of Mr. Daniell, the average quantity of rain which falls in the neighbourhood of London, in the course of a year, amounts to 23.1 inches; the greatest quantity falling generally in the month of July, and the least in February; and the whole quantity falling during the first six months being not much more than half that in the last six months of the year.*

57. Leslie has remarked that in general twice as much rain falls on the western as on the eastern side of the island of Great Britain, and that the average quantity may be reckoned at 30 inches. According to this estimate, the whole discharge from the clouds in the course of a year, on every square mile of the surface of Great Britain would at a medium be 1,944,633, or nearly

How is the rain-gauge constructed and applied?
What depth of rain generally falls in London in the course of a year?

* Meteorological Essays and Observations. By J. F. Daniell, F. R. S. 2d edit.

2,000,000 tons. This gives about three thousand tons of water for each English acre, a quantity equal to 630,000 imperial gallons.*

58. It may be questioned whether the very limited extent of any observations which can be made by means of rain-guages affords ground for perfect confidence in the results they afford; and hence wherever experiments can be prosecuted on a larger scale it is desirable that they should be recorded; as the conclusions already obtained might thus be either confirmed or corrected.

59. There is one singular circumstance attending the fall of rain calculated to throw some doubt on the absolute accuracy of the common mode of observation, which is, "that smaller quantities have been observed to be deposited in high than in low situations, even though the difference of altitude should be inconsiderable. Similar observations have been made at the summit, and near the base of hills of no great elevation. Rain-guages placed on both sides of a hill at the bottom, always indicate a greater fall of rain than on the exposed top."*

60. It appears, however, that larger quantities of rain fall on extended tracts of elevated ground than at the level of the sea; but that at stations abruptly elevated above the surface of the earth the amount diminishes with the ascent. The mean annual fall of rain at Geneva, as calculated from observations during thirty-two years, amounts to 30.7 inches; and on the Alps, at the Convent of the Great St. Bernard, the mean of twelve years is 60.05 inches. According to M. Arago, who has traced a progressive decrease in the annual amount of rain from the equator to the poles, not less than 123.5 inches fall in a year on the Malabar coast, in latitude 11½ deg. N.; while in latitnde 60 deg. the quantity is reduced to 17 inches.

61. The water that falls from the clouds as well as that derived from melted snow and similar sources, if the surface with which it comes in contact happens to be loose and porous, will sink into the bowels of the earth, penetrating in any direction till it meets with a stratum of clay, or some other dense and almost impervious substance, which may cause it to accumulate and form subterrane-

How great a weight of water has Leslie supposed to fall on a square mile of the surface of Great Britain.

What is found to be the relative quantity of rain falling in high and low stations?

How are the quantities of rain found to vary on high table lands, and at the level of the sea?

What remarkable example of this variation can be adduced?

What are the relative quantities of rain falling in the torrid and in the temperate zones respectively?

Explain the manner in which water reaching the earth from the clouds is eventually disposed of?

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* Leslie on Heat and Moisture; see, also, Proceedings of the British Association at Cambridge, 1833, for a report of experiments made at York.—Ed.

ous lakes or reservoirs, the contents of which occasionally are raised to the surface in various situations by hydrostatic pressure. Thus sometimes in digging wells it is necessary to penetrate to a great depth before water can be obtained, but at length when the source is found the water rises with such rapidity in the shaft that has been opened as scarcely to leave time for the well-sinkers to make their escape from the ascending column.

62. The term Artesian wells has been recently applied, especially in France, to wells formed in the manner just described, by the ascent of water through openings made by boring down and introducing tubes which traverse the superior strata, and communicate with subterraneous springs or reservoirs, from which the water rises through the tubes by hydrostatic pressure, nearly or quite to the surface; constituting in the latter case perpetual fountains, such as occur on the eastern coast of Lincolnshire, England, where they are called Blow Wells. They are also frequent in Artois, in the Netherlands, and hence they have derived the appellation of Artesian wells, from Artesium, the ancient name of that country.*

63. Water collected in subterraneous passages by infiltration sometimes passes below the bed of the sea, and forms a sort of Artesian fountains, which flow at intervals depending on the rising and falling of the tide. A remarkable ebbing and flowing stream of this kind was discovered in 1811, by boring in the harbour of Bridlington in Yorkshire;† and submarine fountains have been met with at the mouth of the Rio los Gartos, in South America, at Xagua, in the Island of Cuba, and elsewhere.‡

64. By means of such underground canals formed by nature, streams of water and even great rivers, after sinking into gulfs and cavities in the earth, make their appearance again at the surface, in some cases far from the spots where they descended.§ Gulfs of this kind, in which rivers and rivulets lose themselves, occur in the Alps of Jura, and other limestone mountains; and where the upper surface consisting of a bed of tenacious clay prevents the absorption of the rain-water by the soil, openings into the more porous strata beneath whether natural or artificial, may

What evidence have we of the existence of extensive collections of water under the surface of the ground?

To what is the term Artesian wells applied?

What is the origin of that term?

In what remarkable situation has the formation of Artesian wells been occasionally prosecuted?

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* See Notice of a Lecture on Geology, by Dr. Buckland, in the Report of the British Association, vol. i. pp. 100, 101.

† See a Paper by John Storer, M. D. in the Philosophical Transactions, for 1815. Abst. of Papers in Phil. Trans. vol. ii. pp. 6, 7.

‡ Numerous Artesian wells, both salt and fresh water, have been formed in the United States.—Ed.

§ See Humboldt's Travels, vol. ii. p. 312.

be made the means of converting a marshy waste into a fertile plain.*

65. When rain falls on the summits or elevated sides of hills and mountains, if the surface be solid rock or clay, the liquid, by its natural tendency to flow till every part of its exposed surface has attained a common level, collects in rills, which find or form for themselves narrow channels, through which the water descends to the plains below; there the confluence of springs from various sources produce lakes or rivers, which in general ultimately communicate with the ocean, or with some great inland sea, like the Caspian or the Lake of Aral, both which are below the level of the Mediterranean;† and other lakes which have no outlet must be situated in valleys or basin-shaped cavities, either below the sea-level, or surrounded completely by walls of rock or compact earth, which prevent the egress of the liquid mass.

66. Rivers in their passage to the deep sometimes form grand and beautiful cataracts and waterfalls, where the collective stream, after being confined in a narrow channel, bursts abruptly over a precipice with astonishing force, dashing on the lower surface, and rising again in clouds of misty spray. Such are the famous Falls of Niagara, formed by the water of Lake Erie; the Cataract of Tecquendama, on the Rio Bogota, in South America, described by Humboldt; the Fall of the Rhine at Schaffhausen; and the cataracts of the Nile, at Syene, now Assouan, in Upper Egypt.

67. The currents, which have been thus rushing with impetuous force over the same surfaces for successive ages, cannot but have had a considerable effect even on the hardest rocks of which their beds are formed; and hence the heights from which these torrents descend being gradually worn down, alterations take place, and the cataracts must at length lose much of that formidable and impressive appearance they now exhibit. It is owing no doubt to such changes that the descriptions given by ancient travellers and geographers of some of the most remarkable cataracts by no means correspond with their present state.

68. Rivers formed by nature are running streams, whose velocity depends on the inclination of the surface of the country through which they pass. They have in various ages and in dif-

In what instances is water known to have collected in basins below the level of the sea?

What influence are cataracts known to exercise on the rocks over which they descend?

Why are the accounts of ancient travellers not always verified by the present appearance of cataracts?

On what does the velocity of natural streams depend?

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* See an account of the draining of the Plain of Palans, near Marseilles, by sinking shafts from the surface into the cavernous strata below, which conveys water through subterraneous channels to the harbour of Mion, near Cassis, forming spouting springs, or Artesian fountains.—Arcana of Science for 1832, pp. 235, 236; from Hericart de Thury.

† See the Report of the British Association at York, p. 239.

ferent parts of the world been made the means of intercourse by inland navigation between distant places. For this purpose, however, they are but imperfectly adapted; since, besides the obstacles arising from rapids and cataracts, there must always be difficulty in ascending the stream of a river proportioned to the rapidity of the descending current. Hence in many countries navigation for the purpose of internal communication is in a great degree confined to the larger rivers and tide-ways, and to the numerous artificial canals which have been constructed chiefly since the middle of the last century; and the smaller natural streams, crossed by wears, mills, and manufactories of various descriptions, may thus be most effectively rendered subservient to the promotion of national industry and wealth.

69. A navigable canal usually consists of several continuous bodies of water, sometimes of considerable longitudinal extent, and each one having a perfectly level surface, the water being at rest. In a country intersected by numerous mountain ridges and valleys, the formation of a long unbroken line of canal must in general be attended with difficulties, and can seldom be effected at all except by erecting massive aqueducts supported on arches, and stretching from one point to another over the lower grounds, and elsewhere by carrying subterraneous galleries or tunnels through intervening hills.

70. Canals, however, generally consist of several longitudinal basins at different levels, and to preserve or rather occasionally to form communications between these, for the passage of vessels, locks are constructed wherever a variation in the level takes place, and thus vessels may be raised or lowered, according to circumstances. Locks are nothing more than small basins, with floodgates at each end, placed across the canal, from side to side, and thus including a portion of its water between them. To transfer a vessel from the higher to the lower level, the water in the intervening lock must be raised, by opening sluices at the bottom, to the height of the upper level, then the floodgates on that side being opened, the vessel is to be drawn into the lock, the gates through which it has passed are to be shut, and the water in the lock suffered to sink through sluices to the level of the lower part of the canal, and the lower floodgates then being opened the vessel may proceed on its passage till it reaches the next lock, where the same process must be repeated. The transfer of a vessel from a lower to a higher level is effected by the contrary operation of raising the water in the lock, instead of sinking it, while the vessel remains inclosed in it.

71. The passage of vessels in either direction through a lock cannot take place without the loss of a considerable quantity of

What circumstance limits the usefulness of rivers for purposes of navigation?

Of what do artificial canals commonly consist?

In what manner is a communication effected from a reach of canal at one level to that at another?

water, which must in each case be allowed to escape from the higher to the lower level of the canal. Where the supply of water therefore is not very copious, and more especially when the application of artificial means is requisite to obtain it, the loss becomes a serious inconvenience, and source of expense. This has led to different schemes for the conveyance of canal-boats from one level to another, without any expenditure of water.

72. One method of effecting this object is by means of a suspension-lock or moveable basin, containing a body of water sufficient to float a canal-boat, and capable of being alternately raised to the higher and depressed to the lower level of two corresponding parts of a canal, separated from each other by floodgates, with a space between them in which the suspended basin might be raised or lowered, so as to take in and discharge the boat. This scheme does not appear to have been put in practice, at least not on an extensive scale; and from the complication of the machinery requisite, it would probably be found liable to insurmountable objections. In some situation, the basin terminates at a certain point, and another basin commencing at a lower level, boats are transferred from one basin to another by inclined planes.

Specific Gravity.

73. The terms Density and Specific Gravity have been repeatedly introduced in the preceding pages; and their general signification has been in some degree elucidated already. It will however be necessary now to explain somewhat more fully the signification of those terms, not only as applicable to liquid bodies, but likewise with reference to solids and gases; and to describe the means by which the specific gravity of any substance may be ascertained.

74. In describing the effects of hydrostatic pressure, we have hitherto considered them as owing to the presence of a single liquid; the illustrations of the principles of the science now under review having been chiefly drawn from the phenomena exhibited by water alone, in several situations and circumstances, as affording results more simple and uniform than those which are observed when different liquids are placed in contact with each other, and when their combined pressure on solids as well as their mutual action must be modified accordingly.

75. It has been sufficiently demonstrated that a single liquid, as water, will always stand at the same height in two or more open

What disadvantage attends the transfer of boats from one level to another by means of locking?

What methods have been proposed or employed to obviate the loss of water in the transfer of boats?

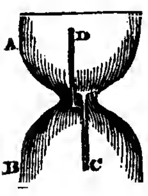
To how many classes of bodies are the terms density and specific gravity applicable?

Whence results the equality of height at which liquids rise in tubes communicating with each other?

tubes freely communicating with each other, whatever may be their peculiar forms or dimensions; and this indeed is a necessary consequence of the common tendency of every liquid to act with equal force in all directions, producing equality of pressure on the solid body or bodies by which it may be encompassed, and extending itself, where unconfined, till every portion of its surface has assumed a common level.

76. When two liquids or any greater number, differing from each other in specific gravity, are placed in contact, as when included in a glass jar or bottle, unless they are capable of uniting to form a chemical compound, it will be perceived that each liquid becomes arranged in a separate and distinct stratum, the heaviest, or that which has the greatest specific gravity, sinking to the bottom of the jar, and presenting a level surface above, on which rests the next heaviest liquid; the others in the same manner taking their places according to their respective degrees of relativo or specific gravity. Thus mercury, water, olive-oil, and sulphuric ether, might be poured into the same phial, in which they would form separate layers, standing one above another, in the order in which they have been mentioned; water being much lighter than mercury, oil lighter than water, and ether yet lighter than oil.

77. Many liquids, differing in specific gravity, may be mixed by agitation so as to form a compound; but if the lighter liquid be poured gently on the surface of the heavier, they will for a long time remain distinct, but little action taking place even where the surfaces meet. Every body knows that water may be mixed with port wine or spirits, both which are lighter than that liquid, as may be shown by the following experiments.

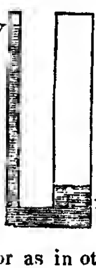


Suppose A B to represent a double-bodied vessel the only communication between the upper and lower portions of which is through the tube C and D; then if the part B be filled with water to the neck, and A with port wine, so as to rise above the tube D, still no mixture or alteration in the state of the liquids will take place, for the lightest occupying the highest situation will retain it undisturbed. But if the lower part be filled with port wine, and the upper with water, the former fluid will ascend through the tube D, and the latter descend through the tube C, till they have entirely changed places. A vessel of this construction, having the upper part transparent, and the lower part opaque, would form an amusing philosophical toy, by means of which might be exhibited an apparent conversion of water into wine. An analogous experiment may be made by taking a

What happens, when two liquids, incapable of chemical union, and of different specific gravities, are put into the same vessel?
With what liquids might this truth be illustrated?
Is the actual mixture of two liquids capable of combining, a certain consequence of placing the one upon the other?
By what arrangement of apparatus might this be exemplified?

small bottle, with a long narrow neck, not more than the sixth of an inch in diameter, which is to be filled with spirit of wine, tinged red, by infusing in it raspings of sanders wood, or yellow, by putting into it a small quantity of saffron; the bottle thus filled with the coloured spirit is then to be placed at the bottom of a deep glass jar of water, when the spirit will be seen to ascend like a red or yellow thread through the water, till the whole has reached the surface.

78. Bodies, differing in specific gravity, and incapable of combination, may be shaken together in a phial, and mixed for a time, but will separate completely on being allowed to remain at rest. Such is the effect exhibited in the following mimic representation of the production of the four elements from chaos. A glass tube, about an inch in diameter, closed at one end, or a deep phial, being nearly filled with equal parts in bulk of coarsely powdered glass, oil of tartar, proof spirit, and naphtha, or spirit of turpentine, the former spirit tinged blue, and the latter red,* the tube or phial must be secured with a cork; and when it is briskly shaken the four imaginary elements will form a confused dull-looking mass, but on setting the phial upright, and suffering it to remain undisturbed for some time, an entire separation will take place between the several portions of the chaotic mixture: the powdered glass at the bottom representing earth; the oil of tartar, floating above it, water; the spirit, with its corulean tint, occupying the place of air; and the glowing naphtha at the top designed as an emblem of elementary fire.



79. When two liquids, varying in specific gravity, are included in a bent tube, as represented in the annexed figure, they will not stand at the same height on both sides of the tube, like a single liquid; but their respective heights will be in the inverse ratio of their specific gravities. Thus, as any given bulk of mercury weighs nearly fourteen times as much as an equal bulk of water, one inch of mercury, M, would equipoise about fourteen inches of water, W, on the opposite side of the bent tube. Neither the form nor the dimensions of the tube are of any importance to the result of this experiment; for as in other cases of hydrostatic pressure, a small quantity of water may be made to counterbalance the larger quantity of the heavier fluid mercury, provided the column of water stands perpendicularly fourteen times as high as the column of mercury.

What happens when two liquids incapable of combination are shaken together?

Describe the apparatus known by the name of the four elements.

What occurs where the bent part of an inverted sypon is occupied by mercury, and one of the branches is afterwards filled with water?

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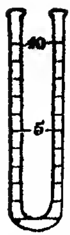
* The blue tint may be communicated to the proof spirit by adding a small portion of tincture of litmus; and the other spirit may be coloured with dragon's blood.



80. On the principle now stated, a ready method might be contrived for ascertaining the relative weights or specific gravities of any two liquids, as oil and water, or water and ether, or spirit of wine. For this purpose it would merely be requisite to procure a glass tube, bent and graduated as represented in the margin; then on pouring into the upright branches, equal quantities by weight of the respective liquids, their relative weights would appear on inspection; being inversely as the heights to which they would rise in the branches of the tube. The accuracy and utility of such an instrument would be augmented by filling the lower portion of the tube with mercury, and the graduated branches being of equal diameter, given weights of any liquids, which would not act chemically on the mercury, would show, by their respective heights on either side, how much greater space an ounce, a dram, or any other quantity of one liquid would take up than an equal quantity of the other; and hence it would appear how far the specific gravity of the latter exceeded that of the former.*

81. As the specific gravity of a liquid is indicated by the relative space which any given portion by weight occupies, so in the same manner the specific gravity of a solid body may be inferred from the bulk of water or any liquid of known specific gravity, which an ounce, a pound, or any similarly ascertained quantity of the solid would displace when plunged in the liquid. On this principle depend the usual methods of determining the specific gravities of bodies, by means of hydrostatic balances, hydrometers, areometers, and oleometers.†

82. The discovery of this fundamental principle of science has been generally ascribed to the Syracusan philosopher, Archimedes, and the circumstances relating to it are thus reported by Vitruvius.‡ Hiero, King of Syracuse, having ordered an artist

How might the principle involved in that experiment be applied to determine the relative weights of different liquids?

What is the relation between the density of a liquid and the space which a given weight of it must occupy?

How may the specific gravity of a solid be found without reducing it to any particular form or bulk?

What instruments are employed to determine relative weights of bodies?

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* An instrument in which the two open ends of the tube are turned downwards and dipped into separate cups of liquids, and to the bent or upper part of which an exhausting spring is applied to produce a partial vacuum to raise the liquid, is much more convenient in practice. It has long been known in France as the "areometre a pompe." A modification by Dr. Hare is called the litrameter.

† The former of these instruments is so called from the Greek Ὑδωρ, water, and Μετρον, a measure; and the latter from Αραιος, light, or having comparative levity, and Μετρον. Oleometers test the value of lamp oil.

‡ Architectur. lib. 9. cap. 3.

to make him a golden crown, after it was completed found some cause for suspicion that the goldsmith had imposed on him by mixing with the gold, with which he had probably been furnished from the royal treasury, an inferior kind of metal. The investigation of this matter was referred to Archimedes, who appears to have been unable for some time to contrive any satisfactory method of ascertaining whether the crown consisted of mixed metal or pure gold. At length, on the occasion of his getting into a bath, he observed that the water rose on the sides of the marble basin or reservoir in which he stood, in exact proportion to the bulk of his body beneath the surface of the fluid. At once the idea flashed on his mind that every solid plunged under the surface of water must displace precisely an equal bulk of that liquid; and as solids, bulk for bulk, are some lighter than others, the comparative or relative gravity of two or more solids might be ascertained by immersing equal weights of them in water, and observing the quantity of liquid displaced by each of the solids. Convinced that he could by this means find out whether Hiero's crown had been adulterated, the philosopher is said to have leaped from the bath, in a fit of scientific ecstasy, which rendered him insensible to every thing except the importance of the principle he had discovered, and running naked through the streets, he exclaimed aloud, "Εὕρηκα—Εὕρηκα." "I have found it out!—I have found it out!"

83. In order to apply his theory to practice, he procured a mass of gold and another of silver, each having just the same weight with the crown: then, plunging the three metallic bodies successively into a vessel quite filled with water, and having carefully collected and weighed the quantities of the liquid which had been displaced in each case, he ascertained that the crown was, bulk for bulk, lighter than gold, and heavier than silver; and he therefore concluded that it had been alloyed with the latter metal.

84. In comparing the relative or specific gravities of bodies, it is necessary that there should be some standard to which the respective weights may be referred. It might be stated that platina is as heavy again as silver, and that cast iron is not much more than half as heavy as mercury; but it would not be possible from these data to decide whether silver would sink beneath the surface of mercury; for though it is clear that cast iron would float on mercury, yet unless some further information were given, no comparison could be made between the relative gravities of silver and mercury. Supposing, however, it be known that mercury is thirteen times and a half the weight of water, silver ten

What historical account is given of the discovery of this method of determining specific gravities?

What process was performed by Archimedes to detect the amount of alloy in Hiero's crown?

What standard is it customary to assume in speaking of the relative weights of bodies?

What renders any such standard necessary?

times and a half, iron seven times and a half, and platina twenty-one times, it will be obvious that the last-mentioned metal would sink in mercury, while silver as well as iron would remain suspended on it.

85. Tables of the specific gravities of a great multitude of bodies have been constructed, showing their relative weights, expressed in numbers denoting in what ratio they exceed or fall below that of water. The adoption of this fluid as the standard of specific gravity is attended with several advantages, which have induced philosophers in general to consider its density, under certain conditions of temperature and atmospheric pressure, as affording a convenient point of comparison to which may be referred the densities of other bodies, whether solids, liquids, or gases.* The extraordinary power of water to resist compression by mere mechanic force, except under such circumstances as can rarely take place,† is one of the advantages it presents; but in the prosecution of experiments of a delicate nature, the pressure of the atmosphere must be taken into the account in order to ensure accuracy in the results of our calculations. Alternations of temperature, as to heat and cold, also affect the bulk of water so considerably as to render it absolutely necessary that any substances, whose specific gravity we wish to ascertain by experimental comparison with that of water, should have the same temperature with the standard liquid, or that allowance should be made for any unavoidable difference of temperature. Purity of the watery fluid is likewise, as may be supposed, indispensably requisite; rain-water carefully distilled, and thus freed from all foreign impregnation, is therefore to be preferred in the prosecution of experimental inquiries.

86. In the London Philosophical Transactions for 1798, is a memoir by Sir George Shuckburgh Evelyn, containing an account of numerous and important experiments on the specific gravity of water, which have served as the foundation of subsequent researches. He found that a cubic inch of pure distilled water, the barometer standing at 29.74 inches, and Fahrenheit's thermome-

What advantages belong to the standard actually adopted, beyond what are possessed by other substances?

What relation has temperature to the method of determining specific gravities?

What is the weight of a cubic inch of water at mean temperature and pressure?

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* The relative density of gases is sometimes estimated by comparison with that of atmospheric air, as the standard: but the ratio of the specific gravity of atmospheric air compared with that of water being known, that of the other gases may be deduced from computation, when their several relations in point of density to atmospheric air have been ascertained; and on the contrary the relations of the other gases to atmospheric air, as the standard of specific gravity, may be computed from a table of specific gravities, including the gases, and referring to water as the common unit of density.—See Treatise on *Pneumatics*.

† See 10—15 of this article.

ter at 66 degrees, weighed 252,587 grains troy. Now it is a well ascertained fact that water attains the utmost degree of density just before it freezes, its bulk being relatively less at 40 deg. of Fahrenheit or 8 deg. above the freezing point, than at any point either higher or lower in the scale.*

87. The difference of the weight of a cubic inch of distilled water at 40 deg. and at 60 deg. is somewhat less than half a grain troy, whence it may be made to appear from calculation that a cubic foot of pure water, at its greatest density, weighs almost exactly 1000 ounces avoirdupois, or 62½ pounds. If, therefore, the specific gravity of water be represented by the number 1000, each of the numbers in the following table will express the corresponding weights of a cubic foot of the several bodies included in it. Thus a cubic foot of pure gold would weigh 19,258 ounces avoirdupois, and an equal bulk of cork but 240 ounces.

88. *Specific Gravities of various Solids, Liquids, and Gases, as compared with Water at 60 Deg.*

Platina, laminated	22,069	Sulphate of Barytes, or Ponderous Spar	4430
purified	19,500		
Gold, cast	19,258	Oriental Ruby	4283
hammered	19,361	Brazilian Ruby	3531
standard, 22 carats	17,486	Bohemian Garnet	4188
Mercury, fluid	13,568	Oriental Topaz	4010
solid	13,610	Brazilian Topaz	3536
Lead, cast	11,352	Diamond	3521
Silver, cast	10,474	Natural Magnet	4800
hammered	10,510	Fluor Spar	3181
Bismuth, cast	9822	Parian Marble, white	2837
Copper, cast	8788	Carrara Marble, white	2716
Brass, cast	8395	Rock Crystal	2653
wire	8544	Flint	2594
Nickel, cast	7807	Sulphate of Lime, or Selenite	2322
Iron, cast	7207		
malleable	7788	Sulphate of Soda, or Glauber Salt	2200
Steel, soft	7833		
tempered	7816	Chloride of Sodium, or Common Salt	2130
Tin, cast	7291		
Zinc, cast	7190	Phosphorus	1770

At what temperature is water at the greatest density?
What is the weight of a cubic foot of water at its greatest density?
What would be the weight in ounces of a cubic foot of platina?
Would a block of silver sink or swim in a bath of mercury? why?
Would a piece of steel sink or swim in melted copper?
What would be the effect of dropping a bar of lead into a pot of melted tin?
How many times more matter in a cubic foot of saltpetre than in a like bulk of water?

* See Treatise on *Pyronomics*.

Nitrate of Potash, or Saltpetre	2000	Honey	1450
Sulphur, native	2033	White Wax	968
Plumbago, or Black Lead	1860	Caoutchouc, or Gum Elastic	933
Coal	1270	Ivory	1917
Sulphuric Acid, or Oil of Vitriol	1840	Isinglass	1111
Nitric Acid	1271	Milk, cow's	1032
highly concentrated	1583	Butter	942
Muriatic Acid, liquid, or Spirit of Salt	1194	Mahogany	1063
Sea-Water	1030	Lignum Vitæ	1333
Ice	930	Dutch-Box	1328
Alcohol	797	Ebony	1177
Proof Spirit	923	Heart of Oak, 60 years felled	1170
Sulphuric Ether	734	White Fir	569
Naphtha	708	Willow	585
Linseed Oil	940	Sassafras Wood	482
Olive Oil	915	Poplar	383
Oil of Turpentine	870	Cork	240
Aniseed	986	Chlorine, formerly called Oxymuriatic Gas	3.02
Lavender	894	Carbonic Acid, or fixed air	1.64
Cloves	1036	Oxygen Gas	1.34
Camphor	988	Azotic, or Nitrogen Gas	0.98
Yellow Amber	1078	Hydrogen Gas	0.08
White Sugar	1606	Atmospheric Air	1.21

89. If the specific gravity of water be represented by 1 instead of 1000, then that of platina will be 22.069, the last three figures being taken as decimals; the specific gravity of standard gold will be 17.486, that of sea-water 1.030, that of olive oil 0.915; and so on throughout the table, the three right hand figures representing decimal parts, except those denoting the specific gravities of the gases, the numbers of which must be thus altered to indicate the relations of their specific gravities to that of water.

Water	1.
Chlorine	0.00302
Carbonic Acid	0.00164
Oxygen Gas	0.00134
Nitrogen Gas	0.00098

Which would sink most rapidly in water, a piece of flint, or one of native sulphur?

When alcohol and linseed oil are put into the same vessel, which will occupy the higher part?

Determine the same, with regard to water and honey—oil of turpentine and cow's milk—proof spirit and naphtha—sulphuric ether and oil of lavender.

When the specific gravity of water is taken as unity, what must we consider the last three figures of each number in the table?

Atmospheric Air	- -	0.00121
Hydrogen Gas	- -	0.00008

90. From the foregoing table it will appear that almost all bodies will float on the surface of mercury; gold and platina, and their alloys, being the only substances known of higher specific gravity than that metalic fluid, except one or two recently discovered metals of rare occurrence.* Many bodies will float on the surfaces of metal while in fusion: and thus earthy and other substances found in metallic ores rise in the state of scoriæ to the surface of the melted metal in the process of reduction. The lava discharged from volcanos is a very dense fluid, partly metallic; and hence stones of vast bulk and weight are frequently seen swimming on its surface while it remains in the liquid state.

91. Most kinds of wood will float on water, and but few, as fir, willow, and poplar, on rectified spirit. The solution of a solid in any liquid increases its density: thus sea-water is heavier, bulk for bulk, than pure water; and an egg which will sink in the latter will swim in brine. Hence it sometimes happens that a heavy laden vessel, after having sailed in safety across the salt sea, sinks on entering the mouth of a river; owing to the inferior specific gravity of the fresh water.

92. The specific gravity of the human body during life is in most cases nearly the same with that of river water, and coincides more exactly with that of sea-water; so that there are probably but few persons who would not float very near the surface of the sea in calm weather. Corpulent people are, bulk for bulk, lighter than those of sparer habits; for the adipose membrane or fat of animals is inferior in specific gravity to water; whilst lean flesh, unless the blood and other juices are drained from it, is of higher specific gravity than that fluid, and bone is proportionally much heavier than the soft parts of the body. Hence it might be inferred that the power of floating on water does not depend entirely on the relative specific gravity of the solids and liquids which enter into the composition of a human body; and accordingly we

Which of the gaseous bodies has the greatest specific gravity?

How many and which of them are specifically heavier than atmospheric air?

Which is the lightest of gaseous substances?

Why do the impurities of metallic ores rise, when melted, to the surface of the mass?

What is the nature of lava ejected from volcanos?

What effect on the specific gravity of any liquid is produced by dissolving in it a portion of any solid?

To what maritime occurrence is this fact applicable?

What is the relative specific gravity of the human body compared with fresh and with salt water respectively?

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* Iridium, a peculiar metallic substance discovered by Mr. Smithson Tennant, in combination with crude platina, has the specific gravity of 18.6; and Tungsten is a rare and difficultly fusible metal, the specific gravity of which is stated to be 17.2.

find that the body of a person destroyed by drowning, or thrown into water immediately after death, will sink far beneath the surface; but after several days have elapsed a body thus treated usually rises to the level of the water, in consequence of its having become specifically lighter than that fluid, from the accumulation of gas within the body, produced by incipient putrefaction. It is then chiefly owing to the air included in the cavities of the body during life, especially that portion contained in the lungs, that a man is enabled to float on the surface of a pond or river.

93. There are, however, some credible accounts extant of persons whose bodies were so much inferior in specific gravity to water, that they could not descend beneath its surface; not possessing that "alacrity in sinking," which may be literally attributed to most individuals. In 1767, there was a priest residing at Naples, named Paulo Moccia, whose extraordinary facility of flotation attracted much public attention. This ecclesiastic could swim on the sea like a duck; when he assumed a perpendicular position, the water stood on a level with the pit of his stomach; and it is stated that when dragged under the water by one or more persons who had dived for that purpose, as soon as he was released, his body would rapidly rise to the surface. It appears that the weight of this gentleman's body was thirty pounds less than that of an equal bulk of water. This peculiarity of conformation doubtless depended partly on his being extremely fat, and having very small bones; besides which, probably his lungs were capable of holding a larger quantity of air than is usual, and there might also have been an accumulation of air in the abdomen, arising from the disease called tympany, or from some other cause.

94. Most very corpulent people, who are at the same time strong and healthy, would perhaps find on trial that their bodies would float on water; and those who do not happen to be endowed with a superabundance of fat might still in almost all cases, with a little application, acquire the habit of floating with facility. The capability of breathing freely and at regular intervals is essentially requisite to enable a person to support himself on the surface of water. The head, and the upper and lower extremities are relatively heavier than the trunk of the human body; and the head especially, from the quantity of bone of which it is composed, is the heaviest part of the whole mass, yet unless the face at least be kept above water respiration cannot be continued. It is therefore of the highest importance that all persons should be

Will a fat or a lean person float with the greater facility in water?
What will generally occur when a human body is thrown into water?
Why does the body of a drowned person rise to the surface after being some days in the water?
What extraordinary instance of specific lightness in the human body is recorded?
On what circumstances did it probably depend?
What operation is it necessary to perform while attempting to float on the surface?

perfectly aware of the precautions necessary for this purpose; so that any one accidentally falling into the water, and being unable to swim, may be instructed how to escape a watery grave.

95. A person suddenly immersed in water, if not absolutely deprived of self-possession by fright, should, on coming to the surface after the first plunge, endeavour to turn on the back, carefully keeping the hands down, with the palms extended towards the bottom of the water, the legs being suffered to sink rather lower than the trunk; the only parts above the surface will then be the face and a small portion of the chest: at each inspiration more of the head and chest will rise above the water, and perhaps those parts will at first be for a moment covered with the aqueous fluid at the interval of expiration of the air. Every thing depends on making no effort to raise or keep out of water any part except the face, and endeavouring to keep the lungs, and consequently the chest as much expanded as possible, without using any irregular exertions in breathing; and it may be proper to caution persons thus circumstanced against struggling or screaming, as worse than useless; for in case any one who might yield assistance should be within call, it would be best to wait till the first alarm had subsided, and then the involuntary bather, conscious of comparative security, might use his voice with due effect, and without increasing the hazard of his situation.

96. But an acquaintance with the art of swimming can alone give a person perfect confidence of safety when by accident immersed in water. It is to be lamented that this is not a more general accomplishment; for it is one which must frequently prove of great utility; and it is much to be desired that it should become a branch of education at schools for boys, as being of higher importance than the more fashionable arts of dancing, fencing, or even gymnastics.

97. It may be questioned whether written instructions alone would enable any one to acquire a facility in swimming; and admitting their utility, it would be inconsistent with the purpose of this work to afford them more than a cursory notice. In swimming, as in floating, the chief object of attention must be to keep the face above water, while the limbs are immersed; but from the different position required, it must be apparent that in swimming, not the face alone, but nearly the whole head must be sustained above the surface. In making a first attempt, the advice of Dr. Franklin may be followed, where he directs the learner to walk into water till he reaches a place where it stands as high as his breast, and dropping into the clear stream an egg; as soon as it has reached the bottom, he is to lean forward, resting on the

What measures should be adopted when one is suddenly immersed in water?

What importance ought to be attached to the art of swimming?

What is the first step towards the acquisition of that art?

How may the learner be made sensible of the buoyant power of the water?

water, and endeavour to take up the egg, when he will become sensible of the upward pressure or resistance of the fluid; and finding that it is not so easy to sink as might have been previously supposed, the young adventurer would acquire confidence in his own efforts, the valuable result of experience.

98. Corks or blown bladders fitted by strings passing under the arms and across the chest, will afford material assistance in supporting the upper part of the body in a proper position; but they perhaps rather tend to retard than facilitate the progress of the learner, by leading him to form a false estimate of the resistance of the water; so that as soon as he makes an experiment without the corks he finds himself obliged to recommence his task, and study it on a different plan which might as well have been adopted at first. If, however, corks or bladders should be used, it is highly necessary that they should be secured from slipping down to the hips, and thus causing the swimmer to fall with the head vertically downwards, and incur the most imminent risk of drowning.

99. As less exertion would be required in the position of floating than in that of swimming, there would perhaps be some advantage in acquiring the power of flotation, as above described, previously to attempting to swim. This having been effected, the learner might, instead of the common expedient of using corks, procure a two-inch pine plank, ten or twelve feet long, and placing it in the water, lay hold of it with one or both hands and push it before him while learning to strike with his legs. But this or any other artificial mode of practice, that may be adopted, should be laid aside as speedily as possible, as the learner cannot too soon make himself acquainted with the full effect of the pressure of the fluid in which he is moving, and with his own strength and power of action; and till such knowledge is attained he will make but slow progress in the art of swimming.

100. The method of communicating buoyancy to solids of greater specific gravity than water, and enabling them to float in that fluid, by inclosing within them air or gas, is susceptible of application to a variety of useful purposes. It has accordingly been adopted in the construction of swimming-girdles, life-preserving belts, and air-jackets, which like the bladders noticed above, are merely bags of different shapes contrived so as to be inflated with air, and worn round the upper part of the body. Life-boats or safety-boats, as they are sometimes called, are rendered buoyant by forming in their sides air-tight cells or lockers, of sufficient dimensions to prevent the boat from sinking even when every other part of it is filled with water. It has recently been proposed to extend this principle to vessels of any size, and thus to prevent

What objection exists to the use of cork jackets and similar expedients to increase the buoyancy of the body when learning to swim.

What use may be made of the swimming board while learning the art?

Explain the construction and use of the girdle employed for the same purpose.

How are life-boats made incapable of sinking?

heavy laden merchant ships or men of war from foundering at sea. The scheme consists in the employment of copper tubes of a cylindrical form, hermetically closed at the ends and sufficiently large and numerous to contain as much atmospheric air as would cause a ship to swim, when in consequence of having sprung a leak it would otherwise sink. It is stated by the inventor of these safety tubes, Mr. Ralph Watson, that an eighty-gun ship, even when immersed from leak, would not require the application of such tubes to a greater extent of displacement of water than would be sufficient to support 240 tons of its immense weight.

101. Fishes, in general, are provided by nature with a peculiar apparatus, which enables them to swim with the utmost facility, and to ascend close to the surface of the water, or descend to a considerable depth beneath it, by means of a membranous bag or bladder containing air, which they can distend or contract, and thus alter their specific gravity according to circumstances. The toad fish it is said distends its stomach by swallowing air, to assist it in swimming, and becomes puffed up like a blown bladder, in the same manner as the globe or balloon fish.

102. An experiment has been previously related exhibiting the effect of the pressure of water upward in supporting a plate of metal, in contact with the lower extremity of an open cylinder, from which it may be inferred that solids of the highest specific gravity, as gold or platina, may be made to float on water or any other liquid, provided the floating body be of such a form that its upper surface may be protected from the pressure of the liquid by a column of air, the depth of which bears a certain proportion to the specific gravity of the solid. It is thus that a china tea-cup, though much heavier than an equal bulk of water, will yet float on that liquid if placed in it with its cavity upwards and empty; but on pouring water into it, the cup will descend in consequence of the air within its cavity being displaced by the heavier fluid; till at length, when so much water has been poured in as to render the cup and water together heavier than a quantity of water equal to the space the cup occupies when immersed to its edge, it will sink to the bottom.

103. A raft will float, because it is absolutely lighter than water, and a life-boat also for the same reason; but vessels in general, from the cock-boat to the largest man of war, owe their buoyancy to their concave form. Hence ships need not be built of fir or any light wood, since not only the heaviest woods might be used but

How are Watson's safety tubes to be applied for the security of vessels at sea?

To what is the power of vertical movement in fishes attributable?

How may the heaviest of metals be made to float on the lightest of liquids?

What quantity of water will it be necessary to pour into a floating basin in order to sink it to the water's edge?

How is the floating of a raft to be explained?

even the heaviest metals, to construct floating vessels; and indeed steam boats made of sheet iron have recently been tried, and found to possess the requisite properties for ploughing the waves with perfect facility and safety.

104. Floating bodies may be employed to raise heavy substances from the bottom of a river, pond, or basin of water. Thus a sufficient number of air-tight casks might be attached by ropes or chains to a large block of granite at the bottom of a river near its entrance into the sea, and the ropes being adjusted to such a length as to keep them strained tightly by the buoyancy of the casks at the lowest ebb of the tide, the block would be raised by the upward pressure of the casks at high water. Perhaps this method of raising or lowering ponderous masses of stone might be advantageously applied to practice in building bridges or piers within the tide-way of a river.

105. The common method of regulating the supply of water conveyed by pipes into a cistern by means of what is called a ball-cock, depends on the action of a hollow globe of such dimensions relatively to the thickness of the metal as to keep it always floating on the top of the water in the cistern. A long wire is connected with the ball at one end, and at the other with a valve or stop-cock, on which it acts as a lever, opening it when the long arm of the lever is allowed to descend by the sinking of the ball attached to that end, when the water falls in the cistern, and on the contrary closing the valve, when, by the rising of the ball with the water, the cistern becomes full, and the lever presses on the valve or cock and keeps it shut, so that the cistern can never be filled beyond the proper height.

106. The power of floating bodies may also be applied in a different manner to the purpose of rendering buoyant other bodies attached to them; and among the various applications of this principle may be noticed the ingenious invention called the water-camel, used in Holland and also in Russia and at Venice, to enable large and heavy laden ships to pass shoals or sand-banks. The method of effecting this object consists of the application of two long narrow vessels adapted to the sides of the ship, and being hollow and water-tight they are filled with water, and then let down, and firmly secured on each side of the ship, after which the water is to be pumped out of them, and the whole mass, consisting of the ship and camel is thus rendered specifically lighter than before, and drawing less water than the ship alone did previously, the shoal or sand bank may be passed without danger of grounding.

How does it differ from that of an iron steamboat?

To what useful purpose may the principle of floatation be applied in connexion with submarine operations?

In what manner is the same principle applied to regulate the access of water to a cistern?

Explain the construction and use of the water-camel?

107. The tendency of a floating body to assume a particular position when partly immersed in a liquid, and to retain or lose that position according to circumstances, may he elucidated by reference to the doctrine of the centre of gravity, as explained with relation to solids.* When a solid body, specifically lighter than water, is placed on its surface, it will sink to a certain depth at which the absolute weight of the body is exactly counterbalanced by the upward pressure of the water. The point at which the entire weight of a body acts with greatest effect must he its centre of gravity; and that point at which the sustaining efforts of the liquid are most effective may be termed the centre of buoyancy, which must evidently coincide with the centre of gravity of the portion of water displaced by the floating body; and if the body he of uniform structure with the centre of gravity of that part of it which is under water. A floating body cannot maintain itself in a state of equilibrium, unless its centre of gravity be situated in a vertical line over its centre of huoyancy, or immediately under that point. In the former case it will be in the state of instable equilibrium, and in the latter in that of stable equilibrium.†

108. Hence the necessity of placing iron bars, stones, or other heavy substances in the hold of a ship by way of ballast when it is not freighted, or is laden with very light merchandize, in order that its centre of gravity may not be elevated too much above its centre of buoyancy. It is not requisite that the centre of gravity should be reduced below the centre of buoyancy, for though such a disposition would contribute to the stability of the vessel, the resistance to its passage through the waves would be so great as to make it sail heavily. In determining the proper situation of those points regard must be had to the shape and dimensions of a vessel as well as to the nature of the cargo or lading, and the manner of stowing it; and on a due attention to these circumstances its security and rate of sailing must in a great measure depend.

109. The methods adopted for ascertaining the specific gravities of bodies are founded on the relation between bulk or dimension, and weight, which may be determined by various operations, according to the nature of the several substances, whether solid, liquid, or gaseous, to which they are applied. The relative den-

What takes place in regard to the centre of gravity of a floating body?
How deep will such a body when specifically lighter than water always sink in the liquid?
What name is given to the point at which the whole buoyancy of the liquid may be conceived to be concentrated?
What will be the relative position of the centre of gravity and of the centre of buoyancy of a body floating at rest on the surface of water?
Why are heavy articles stowed in the hold rather than on the deck of a vessel?

* See *Mechanics*, Nos. 125—133. † Ibid. 137—141.

sity of different solids may be discovered by simply weighing a cubic inch of each; but unless the process of measurement and that of weighing are both executed with scrupulous accuracy the result must be uncertain, and the former of these operations at least, must, in many cases, be difficult, and in some impracticable. Hence the method adopted by Archimedes is to be preferred, and it may be improved by merely weighing the subject of the experiment first in air and then in water, and noting the loss of weight that takes place in the latter case, as that must be equal to the weight of the water displaced by the Substance under examination.

110. On this principle is constructed the hydrostatic balance, which may be used to determine the specific gravity of liquids, as well as that of solids. For this purpose a globular or egg-shaped mass of glass or crystal must be suspended by a hair or fine silk thread from a hook at the bottom of one of the scales of an accurate balance, and its weight is then to be ascertained first in the air, next in distilled water, and lastly in the fluid whose specific gravity is required; then by deducting the loss of weight of the glass in water from the loss observed when it was weighed in the liquid, the specific gravity of the latter, with reference to that of water, will be obtained. By using a glass globe of such dimensions as to lose 1000 grains in water, its loss of weight in any liquid would at once indicate the specific gravity of that liquid.

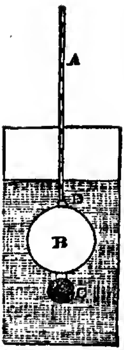
111. Insoluble solids denser than water are easily subjected to experiment; but any insoluble solid body, which is specifically lighter than water, requires, in order that its specific gravity should be ascertained, the addition of some heavier substance, so that the joint mass may be made to sink in water; then its weight in air and in that liquid respectively being determined, the specific gravity of the lighter solid will be the difference between the weight of the heavier body in water alone, and that of the joint mass, deducted from the difference of their weight in air. Solid substances, soluble in water, such as salts, may have their specific gravity ascertained by weighing them in alcohol, or some other liquid which will not dissolve them, and their specific gravity, water, being the standard, may be found by computation; or they may be weighed in water after being defended from its action by coating them thinly with melted bees-wax.

What are some of the methods of determining the specific gravity of bodies?

What is the construction of the hydrostatic balance, and how is it applied to this purpose?

What method is it necessary to adopt in ascertaining the specific gravity of solids lighter than water?

How can we take the specific gravity of solid bodies which are soluble in water?



112. The most usual and convenient method of ascertaining the specific gravities of liquids is by means of a hydrometer. This instrument, as represented in the margin, consists of a hollow glass ball B, with a smaller ball of metal C, appended to it, and which, from its superior weight, serves to keep the instrument in a vertical position, to whatever depth it may be immersed in a liquid. From the large ball rises a cylindrical stem A D, on which are marked divisions into equal parts; and the depth to which the stem will sink in water, or any other liquid fixed on as the standard of specific gravity being known, the depth to which it sinks in a liquid whose specific gravity is required will indicate, by the scale, how much greater or less it is than that of the standard liquid.

Capillary Attraction.

113. Liquids are distinguished by the property of preserving a level surface when at rest, and rising to the same height in any number or variety of communicating tubes; an effect resulting from the joint action of the cohesion of their particles and the influence of universal gravitation. But there are certain circumstances in which liquids may be placed, in consequence of which the phenomena will be remarkably modified, and a portion of a liquid mass may rise far above the common level, and preserve its elevation, as if exempt from the power of gravity. Water may be made to rise perpendicularly to a great height in an exhausted tube; and even mercury, one of the heaviest of fluids, may be seen to be elevated in the same manner in a barometer tube 29 or 30 inches above the level of the liquid in the basin, into which the open end of the tube is plunged. But in these cases, as we shall subsequently show, the influence of gravitation is distinctly perceptible, and the liquids rise in exhausted tubes, in consequence of pneumatic pressure.*

114. There is, however, another case in which liquids rise above their common surface level, not being inclosed in exhausted tubes, but in tubes open at both ends, or between solid plates nearly in contact. This phenomenon is styled *Capillarity*, and is said to be caused by Capillary Attraction.† Instances of the operation of

How are the specific gravities of liquid substances commonly ascertained?

Explain the construction of the hydrometer?

In what manner may water be made to rise above the general level of its mass?

Is the exhaustion of tubes in all cases necessary to produce that effect?

To what phenomenon is the term capillarity applied?

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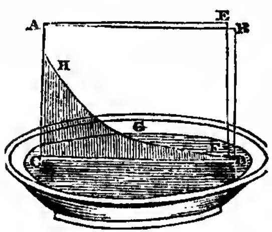
* See an account of the Barometer, in Treatise on *Pneumatics.*

† From *capillus*, a hair, or *capillaris*, hair-like, in reference to the small bore of tubes which produce these effects.

this principle are constantly taking place around us, and though highly interesting, they are overlooked by common observers. If a slice of stale bread an inch square, and three or four in length, be held perpendicularly with one end immersed in a small quantity of water or milk, the liquid will ascend through the pores of the bread till it is entirely absorbed, and if there is a sufficient quantity of it, the bread will become saturated with the moisture. In the same manner water or any aqueous fluid will ascend and spread through a lump of sugar or a heap of sand, if the base of either be immersed in the liquid.

115. Tubes of glass having a very small bore, and therefore called capillary or hair-like, if dipped a little way beneath the surface of water, will cause the liquid to ascend to a height bearing a certain relation to the diameter of the tube. If that diameter be 1-50 of an inch, water will rise to 2½ inches; if it be but 1-100 of an inch, it will rise 5 inches; and so on in the inverse ratio of the diameter of the tube. Similar effects may be exhibited by means of two plates of glass, placed as represented in the margin in a shallow vessel of water, so that their edges on one side, A C, may be in contact, and the other B D and E F, somewhat separated. The liquid will then rise between the plates, standing highest on that side where they most nearly approach, and gradually declining towards the sides that are separated, the upper surface of the elevated portion of the fluid forming the curve F G H, the height of the liquid at any point, as H, being greater in proportion, as it is nearer to the side of the plates A C.



116. It is in consequence of capillary attraction that a sponge imbibes water, blotting paper absorbs ink, or that oil arises amidst the fibres of the cotton-wick of a lamp. These effects are manifestly owing to a common cause, and we learn from experiment that it is only under certain conditions that they take place. Thus, all liquids will not rise to the same height in the same tube, for water will rise higher in a capillary glass tube than alcohol, and neither of these liquids will rise at all in the finest metallic pipe, nor in a glass tube, if the inside of it be greasy. Mercury, on the contrary, will not rise in a clean glass tube, especially if it be wetted; while it becomes elevated, when the inside is lined with a very thin film of bees-wax or tallow.

117. Some remarks have been elsewhere introduced, relative to

From what exhibition of the principle is its name derived?
How may the progressive increase of capillary attraction be experimentally exhibited?
Is the same amount of capillary attraction exhibited by a solid towards all sorts of liquids?

the effect of cohesive attraction on the particles of liquids, causing them to assume a globular figure, and on the modifications produced by the attraction of solids with which the liquids may come in contact.* It is on the joint operation of these causes under particular circumstances that the phenomena of capillarity appear to depend. It is found from observation that when fluids rise in capillary tubes, the surfaces are concave or depressed in the centre; and on the contrary, when the fluids do not rise, they have convex surfaces, or stand highest in the middle. These effects are manifestly owing, in the first case, to the superiority of the attraction between the liquid and the tube over that between the particles of the former; and in the second case, to the inferiority of the former attraction compared with the latter. Hence also if water be poured into a glass tumbler it will rise somewhat at the edges, while mercury poured into the same vessel would be depressed at the edges.†

On what causes do the phenomena of capillary attraction depend?
What surfaces do liquids in tubes ordinarily present?
What causes the diversity in this case?

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* See No. 5 of this treatise.
† See Journal of the Franklin Institute, vol. xiv. p. 147, for some ingenious experiments on capillary attraction, by Mr. J. W. Draper.—Ed.

The following, among other treatises, may be profitably consulted in regard to this branch of philosophy, and will generally, perhaps, be attainable without much difficulty by the American teacher.

Cambridge Mechanics, by Prof. Farrar, p. 289—368.
Fischer's Elements, p. 83—111.
Playfair's Outlines of Natural Philosophy, vol. i. p. 168—193.
Gregory's Mechanics for Practical Men, Philad. edit. p. 284—301.
Library of Useful Knowledge—Treatise on Hydrostatics.
Robinson's Mechanical Philosophy, vol. ii.
Edinburgh Encyclopedia, article *Hydrodynamics.*
Hydrodynamique, Bossut.
Hydrodynamique, Prony.
Traité de Physique, par Biot, vol. i. chap. 22.
Mecanique Celeste, translated by Bowditch, book 10.

HYDRAULICS.

1. When the equilibrium arising from the weight and consequent pressure of liquids is disturbed, motion will take place; and the laws by which it is regulated are the same with those which govern the motion of solid bodies. The velocity of flowing water, like that of falling bodies, depends on gravitative attraction, and is to be estimated on the same principles; and the phenomena exhibited by jets of water, or other spouting liquids, are analogous to those displayed by solids projected through the air, the effects in both cases depending on the operation of similar causes.

2. Among the circumstances which influence the motions of liquids, one of the most important is the weight of the air, producing atmospheric pressure; and to this force the most powerful and useful machines for raising water chiefly owe their efficiency. Such are the various kinds of pumps, fire-engines, and siphons, which are rather to be considered as pneumatic than as hydraulic machines, resembling in their mode of action the barometer and the common syringe; their construction and effects may therefore be most advantageously investigated and explained in treating of pneumatics. Indeed that branch of hydrostatical science, which relates to the motion of liquids, is so intimately connected with the theory of motion, as applicable to all fluids, whether liquid or gaseous, that in a systematic treatise the subjects could not with propriety be separated.

3. At present, we shall confine our attention to the effects of the motion of liquids on different parts of connected masses, or on solids with which they may come in contact; and afterwards briefly notice the construction and mode of action of those machines whose power depends on the weight or pressure of flowing liquids, or on the pressure or impact of liquids on solid bodies.

4. In consequence of the imperfect cohesion of their constituent particles, liquids present some peculiar appearances, when they fall through the influence of gravitation. A continuous solid mass will always remain at rest while its centre of gravity is supported; thus it may be sustained by net-work, or suspended by a line, as securely and steadily as if it were inclosed on all sides; but an unconnected mass, as a heap of sand, can have no common centre of gravity, and therefore to preserve its stability every separate grain must be supported. Water, or any similar liquid, in order to keep it in the state of equilibrium, requires support even to a greater extent than a disintegrated solid, or powder; for such is the peculiar attraction existing between the particles of a liquid,

What laws regulate the motions of liquids?
On what does the velocity of flowing water depend?
What circumstance modifies the motions of liquids?
Under what two general divisions may liquid motions be examined?
What peculiarity is presented by liquids when falling in obedience to gravitation?

that unless the whole mass be supported laterally as well as at the base, it will spread on that side where the pressure is withdrawn till every part has attained a common level. This property, and its effects in producing pressure in liquids at rest, have been already noticed, and those which are exhibited by flowing liquids are now to be developed.

5. When water contained in a deep vessel is suffered to escape from an aperture in the bottom, it flows in a continued stream, formed by the pressure of the liquid acting against that point from which the support has been withdrawn. The combined effect of the hydrostatic pressure, and the cohesion of the particles of the watery fluid causes various movements in the flowing stream, which may be accurately observed by using a glass jar, and mixing with the water some very small pieces of amber, or sealing-wax, the specific gravity of which exceeding that of water but in a trifling degree, they will be carried down with the current, and exhibit its internal motions.

6. The annexed figure will serve to show the manner in which the liquid descends, at first in horizontal strata, and afterwards, when a portion has escaped, the surface becomes depressed in the centre, till at length, when it approaches the bottom, it assumes the form of a funnel, or hollow inverted cone, which it retains till the vessel is nearly emptied. If the aperture be made in the side of the vessel, and close to the bottom, the same appearances may be observed, with the exception of the hollow cone, which in this case does not occur, the liquid remaining level at the surface till it sinks down to the orifice. As the common direction of the particles of the descending liquid is towards a central point, indicated by the course which the floating fragments of sealingwax take towards the aperture, the stream must become compressed, and consequently somewhat contracted at that point. Its situation depends much on the size of the aperture; and when that is very small, and the side of the vessel in which it is pierced extremely thin, the greatest contraction of the jet will take place at the distance of about half the diameter of the orifice beyond it; and at that point the diameter of the liquid vein will be to the diameter of the orifice nearly in the proportion of 5 to 8, whatever be the height of the liquid in the vessel from which it flows. This contraction of the liquid vein may be equally observed when the discharge takes place from an aperture in the side of a vessel, and likewise when the liquid is projected vertically upwards, as in *jets-d'eau.*

What force projects and maintains the continued stream of water flowing from a deep vessel?

How may the interior motions in such a vessel be rendered apparent?

What appearance on the exterior of an orifice results from the interference of the particles of liquid seeking the outlet?

Within what limits does the *contracted vein* approach the diameter of the orifice?

7. The point of greatest contraction in a stream of flowing water, or of any other liquid, must manifestly be also the point where it has the greatest velocity, as it is there that the hydrostatic pressure acts with greatest effect. In estimating the velocity of a liquid issuing from an aperture in the side or the bottom of any vessel, it will be found to depend on the vertical height of the water within the vessel; and in every case it will be equal to the velocity that a body would acquire in falling through a space equal to that height. Hence it cannot be uniform unless the water is supplied as fast as it is discharged, and thus kept always at the same level.

8. Suppose two vessels, one of which is 5 inches in height, and the other 20 inches, to be filled with water, each having a circular orifice at the bottom 1-5 of an inch in diameter, if both be opened, and the vessel kept constantly full by a supply of water above, the taller vessel will discharge about 21 ounces of water in a quarter of a minute, and the shorter vessel about 11 ounces in the same space of time. Thus, estimating the relative velocity of the stream in the two vessels by the quantities discharged by each in a given time, that of the stream from the taller vessel will be to that from the shorter, as 2 to 1, nearly; and the velocities would be exactly in that ratio, but for the effect of friction between the particles of the liquid and the sides of the vessel, and the resistance of the air, which proportionally diminish the discharge from the taller vessel somewhat more than that from the shorter one. Now taking the velocities as 2 to 1, the height of the taller vessel being to that of the shorter as 4 to 1, it will appear that the velocity in either case is as the square root of the height of the column of liquid in the respective vessels; for $1 \times 1 = 1$, and $2 \times 2 = 4$.

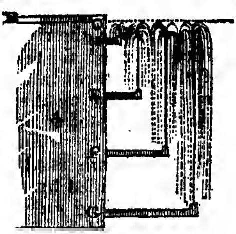
9. It may, therefore, be generally stated, that independently of the irregularities occasioned by friction and other causes, the maximum velocity with which a liquid flows from an aperture in the side or bottom of a vessel will be as the square root of the depth of the vertical column within the vessel. Hence the velocity of a flowing liquid depending, like that of a falling body, on gravitation, it follows that a stream issuing four feet below the surface of a liquid mass will have double the velocity of one issuing at 1 foot below the surface; at the depth of nine feet the velocity will be treble, at 16 feet fourfold, at 25 feet fivefold, and so on in proportion to the depth of the aperture below the surface. It must be recollected that these comparative estimates are to be regarded as results deduced from the influence of gravitation alone, therefore in practice allowance must be made for the effect of friction and atmospheric resistance, and the dimensions and form of the aperture must likewise be attended to in making experiments and calculations.

In what part of a jet will the greatest velocity necessarily be found? On what circumstance does the velocity of issuing currents depend? Why does not the rapidity of flowing liquids correspond exactly with the square roots of the heights, or heads of pressure?

10. From the experiments of Bossut it appears that the actual quantity of water discharged from orifices of the same dimensions, under different degrees of pressure, is far less than might be inferred from calculation. The following table* of theoretical and practical discharges through circular orifices one inch in diameter will clearly exemplify this principle.

Height of the liquid above the orifice.	Computed discharge per minute, in cubic inches.	Actual discharge per minute.	Per ct.
1 foot	4427	2812	63,5
5 feet	10123	6277	62,0
10 feet	14317	8860	61,8
15 feet	17533	10821	61,1

11. The phenomena exhibited by spouting liquids when the current is directed vertically upwards, are equally with those of descending currents under the influence of gravitation; and as bodies projected perpendicularly in the air rise to a height equal to that from which they must have descended, to acquire the velocity with which they were propelled,† so liquids spouting from a short pipe directed upwards, rise to a height equal to that of the liquid column by the pressure of which they were ejected. In the marginal figure let A represent a cistern filled with water at the constant height B C, then if four bent pipes D, E, F, G, be inserted at different distances below the surface, the jets will all rise to nearly the same level, that of the line B C. The resistance of the atmosphere and the mutual friction between the particles of the ascending current, both, however, counteract its force, so that it is only when the orifices of the pipes are extremely small that the elevation of the jets becomes considerable relatively to the hydrostatic pressure. Yet water may be made to rise in spouting streams even above the level of the reservoir from which it issues, by introducing a current of air in such a manner that it may be mingled with the stream, and the fluid thus becoming specifically lighter than the water in the reservoir, the latter is more powerfully acted on by the incumbent weight.



What do the experiments of Bossut prove in regard to the discharge of water from orifices under different heads?

Does the difference between the theoretical and the actual discharge increase or diminish by an increase of head?

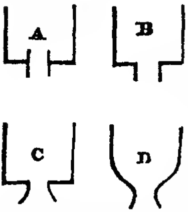
What relation exists between the head of pressure and the height to which a liquid will be projected upwards?

In what manner may a liquid be made to rise in a jet above the level of the source?

* See Encyclop. Metropol.—Mixed Sciences, vol. i. p. 210.

† See treatise on *Mechanics*, No. 91.

12. The concourse of the aërial and aqueous fluids produces musical sounds, somewhat resembling those from the harmonica, but not so soft. That the sounds are caused by the particles of the air striking against those of the water is evident, because, when the flux of the water is stopped, and the air suffered to issue alone, nothing is heard but a hissing noise very different from the preceding.*



13. It has been ascertained from experiment that a greater quantity of water will be discharged in a given time from the side or bottom of a vessel, through a short projecting tube, than from a simple aperture of the same dimensions. The tube, however, must be entirely without the vessel, as in fig. B, for if it is continued inside, as at A, the discharge will be lessened instead of being augmented. Much also depends on the figure of the tube and that of the bottom of the vessel, since more water will flow in the same time through a conical or bell-shaped tube than through a cylindrical one, and a further advantage will be gained by giving a corresponding shape to the bottom of the vessel, as at D. These effects depend on the interruption to the conflux of the aqueous particles by the sides of the rising tube in the vessel A, and the greater facilities afforded for their escape in different degrees by the forms of the apertures in the vessels B, C, and D; and the last of these, coinciding most exactly with the figure of the flowing stream, is best adapted to promote the discharge of the liquid.

14. When pipes, or tubes, of considerable length are used to conduct water from a fountain, the effects will be modified by various circumstances, the quantity discharged depending on the length and dimensions of the pipes, their direction or inclination, and the number and abruptness of the angular bendings which take place in their course.

15. When a stream of water is propelled through a cistern or basin containing water at rest, it will have such an effect on the entire mass as to set it in motion, and cause a great part of it to mix with the current, and make its escape. Owing to this property of flowing liquids, it is possible to drain a lake or marsh by leading a stream descending from a higher level to the border of the lake, when it will sweep through the stagnant water, and

What phenomenon accompanies a jet of mixed air and water issuing from a pipe?

On what circumstances do the effects of short tubes of *adjutage* depend?

What additional causes of resistance are to be considered in long tubes?

What occurs when a stream of water is directed along the surface of a basin of the same liquid?

To what is this effect attributed?

* V. Beudant Traite Elementaire de Physique, 1829, pp. 271, 272.

gradually drawing it into its vortex, carry it off over the opposite bank. Venturi, an Italian philosopher and engineer, made use of this method to drain a marsh near Modena, by conducting through it a rapid descending stream.* This effect is produced by friction between the particles of the liquid, and thus the water in motion communicates its impulse laterally, till the whole mass is affected, and gradually entering the current is carried off.

16. The friction which takes place between the particles of water and those of the air is productive of some curious and interesting phenomena. To this cause is owing the current of air caused by the fall of water from an eminence, of which a remarkable instance is adduced by Ventnri, in a cataract which rushes from the glacier of Roche Melon, on the rock of La Novalese, near Mount Cenis.

17. The agitation of the sea by the wind, and the transformation of its surface into a mass of foaming waves and mountain billows during a storm, is another important and striking effect of the friction of air and water. That the formation of waves depends on this cause is convincingly proved by the experiments of Dr. Franklin, who ascertained that by pouring oil on the surface of a pond to the windward, in stormy weather, the ripples with which it was covered might be made to subside; and it appears that this method of calming the waves by pouring oil on their surface has in some instances been found advantageous at sea. From its inferior specific gravity the oil forms a floating film, which defends the surface of the water from contact with the currents of air, and the friction between the wind and waves is vastly diminished, in the same manner as that which takes place between solids is by the application of unctuous matter.

18. The effect of the pressure or impact of flowing liquids on solids immersed in them, is, as in other instances of hydraulic pressure, greatly influenced by circumstances, and therefore the general principles arising from theory must be adopted with considerable limitations when applied to practice. It must be manifest that when a flat solid surface is moved perpendicularly against a liquid, the resistance will always be in a certain proportion to the extent of the solid surface; and when such a plane surface is exposed to the action of a flowing liquid, the effect must be greater or less according to the degree of the velocity of the stream. Hence may be deduced the general rule, that the effect produced by the pressure of flowing water, acting perpendicularly on a flat surface plunged beneath it, is in the compound

To what useful purpose has this experiment been converted?
How is the elevation of waves to be explained?
What experiment is conceived to demonstrate the correctness of this explanation?
In what proportions are solids resisted when moving through liquids?

* See Leslie's Elements of Nat. Philosophy, vol. i. pp. 397, 398; and Nicholson's Journal, 4to. 1798.

ratio of the square of the velocity of the stream and that of the solid surface. If the surface be presented obliquely to the direction of the stream, the effect must be less than when it is perpendicular to the surface of the current; and the diminution of pressure arising from such a cause will be proportioned to the inclination of the solid surface. Its amount in any given case may be calculated on the same principles as the effects of inclined planes in mechanics.

19. When a liquid acts by impact on a solid plane, causing it to turn round an axis, in the manner of the float-boards of a water-wheel, there will be a certain point in that plane, where, if the whole force of the stream could be concentrated, it would produce the same effect as when that force is distributed over the whole surface of the plane. The point thus indicated is the centre of percussion, some notices of which have been introduced elsewhere.*

Hydraulic Machines.

20. The object of hydraulic machinery is chiefly that of raising water from a lower to a higher level, which effect may be produced by hydrostatic pressure or impact, on liquids and solids, either alone, or in conjunction with atmospheric pressure. The construction of those machines whose operation depends on the latter cause must be referred to the treatise on Pneumatics; but there are other machines which may be properly noticed at present as their modes of action admit of satisfactory explanation on the principles of hydrostatic science.

21. These may be distinguished into three classes: namely, machines for raising water by mechanical means only; those which act by the weight, pressure, or impact of water, on solids; and those in which the effect is produced by the reactive force or intermitting action of flowing water.

22. A common draw-well, from which the water is lifted by means of a bucket and windlass, affords an example of a machine of the first class. But the comparatively small quantity of water that can be raised at once by the use of a single bucket confines its employment to domestic or occasional purposes.

23. The chain-pump is a much more efficient engine, though very similar in its mode of action to the preceding. The figure

What advantage is possessed by the obliquity of the surface against which the resistance is applied?

At what point in a float-board may the whole action or reaction of a liquid be conceived to be applied?

On how many different principles are machines for raising water constructed?

Into how many classes are those machines divided, which depend for their efficiency entirely on hydrostatic laws?

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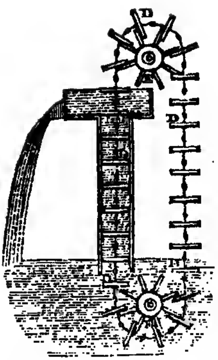
* See *Mechanics*, No. 123. See Col. Beaufoy's experiments on Hydraulic action, in which a vast variety of forms, velocities, and modes of action are detailed.—Ed.



in the margin represents it as consisting of a number of plates or flat disks of wood, D D D D, attached horizontally to an endless chain, and passing round two wheels, E and F, by turning which the chain and plates are carried through a water-tight cylinder, the lower end of which is plunged beneath the surface of water, and its internal dimensions are exactly adapted to receive the plates, which successively entering the tube when drawn up by the revolving chain, form so many buckets filled with water, which they carry up and discharge into a cistern above, or when used as they commonly are on ship-board, into a pipe that may discharge it again into the sea. The machine may be set in motion by a winch, or other means applied to turn the upper wheel. The chain-pump will act with greater effect when the cylinder can be placed obliquely than when its direction is exactly vertical.

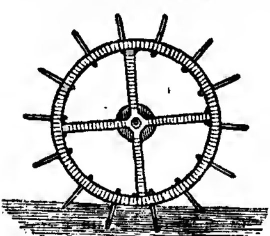
24. The rope pump is a less efficient modification of the chain-pump or bucket-engine. It is composed of wheels, one under water and the other above, having on their peripheries several grooves, through which pass endless ropes of very loosely spun wool or horse hair; and the upper wheel being made to revolve with great velocity, the water which adheres to the coarse ropes may be raised and discharged above by pressure. The water is here attached to the rope by simple cohesive or capillary attraction.

25. The Persian wheel, which is used to raise water not only in Persia but also in Egypt and other eastern countries, consists of a large wheel, to the nave of which are suspended a number of buckets, in such a manner that in the revolutions of the wheel they successively dip into a pond or stream of water over which the wheel moves, and the buckets thus being filled ascend with their load till each in turn reaches the summit of the circuit, where there is a contrivance for tilting each bucket, so that it may discharge its contents into a cistern or reservoir, and it then descends with the revolving wheel to be filled again. Such a wheel may be put in motion by any mechanical means; or if it be employed to raise water from a running stream, float-boards may be added to make it revolve like an under-shot wheel.

Explain the action of the chain-pump.
In what position will the chain-pump act to most advantage?
By what species of mechanical action is water raised on a rope pump?
Explain the construction of the Persian wheel.

26. The cochlion or screw of Archimedes, derives its designation from a prevalent opinion that it was the invention of the Syracusan sage. But it is not mentioned by Vitruvius among the discoveries of Archimedes, and there is some ground for believing that it was, before his time, used in Egypt to raise and carry off the superfluous water left in the low grounds after the inundations of the Nile; so that the question as to its origin remains undecided. Its form, as represented in the margin, is that of a helix (as the name partly implies,) consisting of a flexible tube like a hollow corkscrew wound round a solid cylinder, which may be made to revolve by turning a winch, or by attached wheel-work. When it is placed in an oblique position, with the lower opening of the screw immersed in a cistern, or any other body of water, the liquid will enter below, as the orifice dips beneath it in each revolution, and be carried up and discharged above; the peculiar form of the machine facilitating the elevation of the water.

27. The most important machines belonging to the second class are different modifications of water-wheels. They are respectively termed undershot wheels, overshot wheels, and breast wheels.

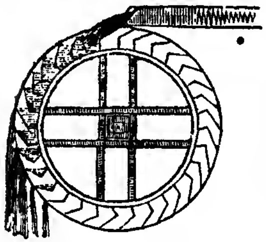


The undershot wheel is said to be of earlier origin than the others; and it is likewise the most common. It consists, as is shown in the annexed figure, of a wheel on the periphery of which are fixed a number of flat boards at equal distances, and set at right angles to the plane of the wheel. They are called float-boards; and the wheel being so placed as for its lowest point to be immersed in flowing water, it is set in motion by the impact of the water on the boards as they successively dip into it. As a wheel of this kind will revolve in any stream which furnishes a current of sufficient power, it may be used where the descent of the water is by far too trifling to turn a breast wheel, much less an overshot wheel.

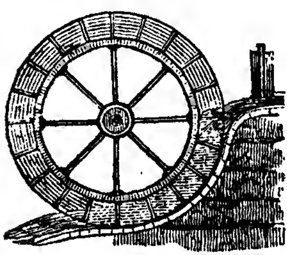
28. If all the float-boards are vertical to the centre of the wheel,

To whom is the invention of the cochlion commonly ascribed?
Into how many classes are vertical water-wheels divided?
What name is given to that part of an undershot wheel which receives the impact of the water?
In what situations is the peculiar advantage of this kind of wheel to be obtained?

as in the figure, the wheel will work equally well in either direction, and one of that construction may therefore be advantageously used in the tide-way of a river, as it will revolve either with the flowing or the ebbing tide. But in any other situation a wheel is to be preferred in which the float-boards incline towards the current, and thus the effect of the stroke is increased; but it appears from experiment that the best position is when the inclination of the float-boards is but inconsiderable.



29. The overshot wheel differs from the foregoing in the manner in which it is acted on by water, receiving its impulse not from the impact only, but from the weight of water. This kind of wheel, as may be conceived from the figure in the margin, can only be used where a considerable fall of water can be obtained. On its periphery are fixed a number of cavities called buckets, being closed on both sides, but having openings, so that the water, conducted by a level trough of the same breadth with the wheel, may fill each bucket in succession, as it reaches that point in the circuit of the wheel at which the weight of the water can begin to act on its circumference. From the peculiar form of the buckets they retain the water partially till they have descended to near the lowest point of the circuit, and having discharged their contents into the tail-stream, they ascend on the opposite side to be filled as before. As the overshot wheel requires the greatest fall of water to make it act, so is it likewise the most powerful with reference to the effect produced, by the momentum of flowing water.



30. The breast wheel is a sort of machine having an intermediate character compared with the undershot and overshot wheel. It has float-boards like the former, but they are converted into buckets somewhat after the manner of those in the chain pump, as they move in a cavity adapted to the circumference of the wheel, as shown in the margin. The water passes through this cavity, enter-

How are the floats of an undershot wheel to be set with respect to the centre?

Describe the construction and action of an overshot wheel.

What relation has the power of the overshot wheel to that of other wheels using the same quantity and fall of water?

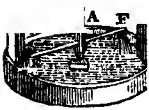
What is the construction of the breast wheel?

In what points does it resemble the other two forms of water-wheels?

ing it nearly on a level with the axis of the wheel. In this case the liquid acts chiefly by its weight; and the machine, though less efficient than the overshot wheel, is more so than the other. It is, therefore, only used where the fall of water happens to be peculiarly adapted for the purpose.

31. Among the hydraulic machines belonging to the third class, which derive their power from the reaction of flowing water, is one called Barker's Mill, as having been invented by Dr. Barker, towards the close of the seventeenth century. This engine, as

represented in the annexed figure, consists of a hollow cylindrical metal pipe, A B, of considerable height, and terminating above in a funnel-shaped cavity. The pipe is supported in a vertical position, by resting below on a pointed steel pivot, turning freely in a brass box, adapted to receive it; and the upper part has a cylindrical steel axis, C D, passing through a board, supported by uprights at the sides. The hollow tube, A B, communicates with a cross tube, E F,



closed at the extremities, but having adjustible orifices at the opposite sides, near each end of the cross tube. A pipe, G, above, communicates with a supply of water, which it discharges into the funnel at the top of the vertical pipe B; and the supply must be so regulated that the pipe may be kept constantly filled with water without running over; while the orifices in the cross-pipe at E and F will deliver the water with a force proportioned to the height of the column in the tube A B, and the apertures being in opposite directions, the spouting currents will communicate a rotary motion to the vertical tube and its axis C D, to which may be attached a toothed wheel connected with any other machinery.

32. The action of this machine does not, as sometimes stated, depend on the resistance of the atmosphere to the jets from the cross-pipe; but is wholly owing to the hydrostatic pressure of the column of water in the vertical tube, which exerting great force on the interior of the horizontal tube, and that force being removed from the points whence the water issues, the pressure or reaction on the corresponding points on the opposite parts of the interior of the tube tends to make it revolve, the action of both jets producing motion in the same direction. Hence it is often called the reaction wheel. The theoretical investigation of its peculiar properties and mode of action, has engaged the attention of the celebrated mathematicians, Leonard Euler and John Bernoulli,

By what mechanical property does the water produce its effect on this wheel?

On what principle is Barker's mill constructed?

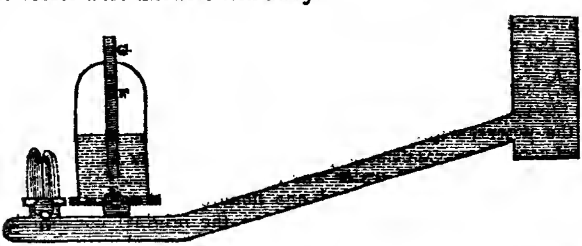
Is the presence of the air necessary to the action of this machine?

On what part of the revolving arms is the moving force really exerted?

both of whom represent it as exhibiting a method of employing the force of water as a moving power, superior to any other.

33. Among machines whose effects depend on the force of flowing water may be included the Hydraulic Ram, invented, or rather improved by Joseph Montgolfier, distinguished for his share in in the invention of the air-balloon. The hydraulic ram operates chiefly from the momentum of a current of water, suddenly stopped in its course, and made to act in another direction; and as it produces a kind of intermitting motion, owing to the alternate retreat and access of the stream, accompanied with a noise arising from the shock, its action has been compared to the butting of rams; and hence the name of the machine.

34. Several historical facts, in regard to the employment of the percussive force of liquids to elevate portions of their own mass, are cited by writers on this subject, prior to the invention of Montgolfier's *Belier hydraulique*. The fixing of pipes to convey water from one level to another, could scarcely fail to render apparent the immense power momentarily exerted when a column of water descending with considerable velocity is suddenly arrested. A most striking example of this was exhibited (Dec. 1834) at the Philadelphia water works, in which, by a little derangement in the action of the valves of the force pump, the column of water from the basin 100 feet high, was suddenly met by the machine with a force which burst the air vessel with an explosion like that of artillery, tearing asunder the cast iron at a part where the diameter of the vessel was three feet, and the thickness of the metal full an inch and a half of perfectly sound casting. Several inch bolts of wrought iron which had confined the upper part of the vessel were likewise torn away.



35. The essential parts of the hydraulic ram, as exhibited by Montgolfier, are represented in the marginal figure. A, is a head of water, connected with the tube or tunnel B, closed at the extremity C, but having an aperture at D, to which is adapted a valve formed by a ball of porcelain or copper, hollow, so as to be not

On what principle is the hydraulic ram constructed?
What remarkable effects of the percussion of a liquid column have been observed?
Explain the several parts of the machine invented by Montgolfier.

more than as heavy again as an equal volume of water, and supported near the orifice by a sort of muzzle or cage. F, is a reservoir of air, with an opening from tho tunnei B, and a valve E fitted to it, but lifting upward, and prevented from displacement by a muzzle over it. From near the bottom of the air-vessel F proceeds a pipe G, which may be continued to any given height to which it is requisite that the water should be raisod. The tube B, is called the body of the ram; the tube G, the tube of ascension; D the stoppage valve, and E the ascension valve.

36. Now the former valve being open and the latter shut when the water begins to run, it at first escapes through the stoppage valve D, but soon acquiring a momentum, from the accelerating velocity of its fall, it drives the ball D against the opening and stops the passage in that direction; the reflected stream then strikes up the valve E, and water enters into the air-vessel F, through the ascension valve: the ball D, as soon as it is relieved from pressure, falls into its muzzle, and makes way for the water again to escape through the stoppage valve, while the other valvo closes through its weight and the reaction of the compressed air in the reservoir. The renewed momentum of the stream presently shuts the stoppage valve, and lifting the ascension valve, more water enters the air vessel, and as soon as the orifice of the pipe G becomes covered, the pressure of the air drives the water upward; for that which has been admitted through the ascension valve cannot return, and more being added at each stroke of the engine, it may be gradually raised to an indefinite height.

37. The absolute effect produced must, in any given case, depend on the fall of water to supply the engine, and the diameter and lengths of the tubes. Montgolfior erected a water ram in his garden, with an artificial fall of water of 7½ feet, by which water was raised to the height of 50 feet, in tubes two inches in diameter: the water expended in four minutes was 554 pints, that elevated 52 pints. Comparing the *power expended*, ($554 \times 7.5=4155$,) with the effect obtained in this case, ($52\times50=2700$,) we get the result $2700\div4155=,65$, or the effect is sixty-five per cent. of the power, while with the best forms of overshot wheels the effect sometimes exceeds 85 per cent. In another machine, with a fall of about 34 feet, water was raised seven times that height, and the stoppage valve closed one hundred and four times in a minute. Improvements were made on the original construction of the hydraulic ram by the son of the inventor, who obtained, in England, a patent for his construction.

Why does not the stoppage valve remain permanently in contact with its seat when once elevated by the force of the current?

On what does the absolute effect of the hydraulic ram depend?

What proportion did Montgolfier find between the *power expended* and the *effect produced* in the elevation of water?

The subject of hydraulics embraces two different objects.— The first, a theoretical view of the nature of the forces exerted by water in motion, and the peculiar phenomena accompanying its movement, whether in open channels, closed pipes, or the organs intended to receive and employ its mechanical efficiency; and the second regards it as a branch of engineering. Teachers will find the two departments often blended together, and the topics belonging to both promiscuously treated. But in some recent publications they have been very properly distinguished, and the science of the matter, with its various theoretical developements, arranged under appropriate heads. In this manual, the object of which is to treat chiefly of the sciences, the former class of treatises deserves particular mention.

Theoretical calculations are to be found in Cambridge Mechanics, pp. 369—417.

Gregory's Mathematics for Practical Men, pp. 302—329.

Treatise of Mechanics, by the same author, 2 vols. 8vo. 1826.

Venturi's Experimental Inquiry, translated by Nicholson.

Lectures on Natural Philosophy, by Dr. Young.

Belidor's Architecture Hydraulique.

Prony's Nouvelle Architecture Hydraulique.

Dubuat's Principes d'Hydraulique.

Traité Elémentaire d'Hydrodynamique, par Bossut.

The volume of the transactions of the British Association at Cambridge, contains an able report by Mr. Rennie, on hydraulics, as a branch of engineering, which has been republished in the Journal of the Franklin Institute for January and February, 1835.

For an account of experiments on water power the reader may consult Smeaton's Reports, Evan's Millwright's Guide, Banks on Mills, and Journal of the Franklin Institute, (report of committee on water-wheels.)

PNEUMATICS.

1. The object of that branch of physical science which has been denominated Pneumatics,* or Aërology,† is to explain and illustrate those phenomena which arise from the weight, pressure, or motion of common air or other fluids possessing the same general properties. The distinction between liquids and those more elastic fluids called air, gas, vapour, or steam, depends in a great degree on occasional causes, especially on temperature and pressure. Those effects which are to be attributed to the operation of heat and cold, or diversity of temperature, are on several accounts of sufficient importance to be made the subject of detached investigation, comprehending a review of the relations of heat to all natural bodies, whether solids, liquids, or gases; and tracing the general influence of temperature in the production of those peculiar forms of matter. Therefore, though it will be impossible to explain the phenomena of atmospheric pressure, and its effects on solids and liquids, without adverting to the influence of temperature, a more extended survey of that important subject must be referred to the subsequent treatise on that branch of science which has been termed, Pyronomics, or the laws of heat.

2. There are two kinds of aëriform bodies; namely, those which are always in the gaseous state, under common circumstances of temperature and pressure, thence named permanent gases or airs; and those which become gases chiefly at high temperature, and which therefore may be styled non-permanent gases or vapours. Common air, or atmospheric gas, affords an obvious specimen of a permanent elastic fluid, and steam or vapour of water of a non-permanent elastic fluid.

3. These different species of gases possess many properties in common; and there is reason to believe that those gases which have till recently been regarded as capable of existing only in the form of permanently elastic fluids, might be reduced to the liquid state by subjecting them to extremely low temperature and very powerful pressure.

4. Mr. Faraday has effected the condensation to the state of a liquid of the gas called carbonic acid or fixed air, as well as several other gases previously considered as permanently elastic

What is the object of the science of pneumatics?
On what rests the distinction between liquids and gaseous bodies?
What imponderable agent is necessarily involved in the phenomena of atmospheric action?
How many kinds of aëriform bodies are found in nature?
What constitute their distinguishing properties?
What has Faraday proved in regard to the state of carbonic acid and other gaseous bodies?

* From the Greek Πνευμα, breath, or air; or Πνευματικος, aërial.
† From Ἀηρ, air; and Λογος, a discourse, or treatise.

fluids, by the combined operation of pressure and low temperature.* And Mr. Perkins, whose experiments on the compressibility of water have been already described, extended his operations to gaseous bodies, and from his statements it appears that he succeeded in reducing atmospheric air to the state of a limpid liquid, by a pressure equal to the weight of twelve hundred atmospheres.† Should the observations of those gentlemen be confirmed and extended to all those now called permanent gases, it will be evident that their existence in the liquid or gaseous form depends entirely on their relations to temperature and pressure, the various airs and vapours being all susceptible of condensation under different circumstances.

5. Airs and vapours, or permanent and non-permanent elastic fluids, however, though they may be considered as forming but one class of bodies, yet from the vast diversity of their relations to heat, admit of being applied to very different purposes; and hence, in treating of their physical properties, the distinction between them must be carefully kept in view. It will, therefore, be conducive to perspicuity to notice in this treatise the properties of the permanent gases, such as atmospheric air; leaving the circumstances which constitute the discriminating characteristics of the non-permanent gases, and especially of steam or the vapour of water, to be more fully investigated in the division of this work, appropriated to the doctrine of Heat.

General Properties of Air.

6. Common or atmospheric air is an invisible or perfectly transparent fluid, the ultimate particles of which appear to be destitute of cohesion; and hence air has a disposition not only to sink down, and spread out laterally like liquids, when unconfined, but it is also equally capable of expansion upwards; so that any portion of this fluid will speedily become dissipated and lost, unless it be inclosed within a solid air-tight vessel or other receptacle, such as a bladder, or retained in an open vessel by the pressure of a liquid on its surface.

7. That air is porous in a very high degree appears from its readily yielding to pressure; but like all material bodies it possesses the property of impenetrability, for though a considerable bulk of this fluid may be forced into a comparatively small space, there must be a limit beyond which the utmost pressure will cease to have any effect. The resistance of air to pressure may be

What effect did Perkins obtain by subjecting air to the pressure of 1200 atmospheres?

To what conclusions are we conducted by these experiments on gaseous bodies?

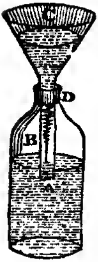
What are the most striking sensible properties of atmospheric air?

What appears to be the mutual relation of its particles to each other?

* See Abstracts of Papers in Philos. Trans., vol. ii. p. 192.

† Idem, p. 290.

demonstrated by means of a syringe of any kind with a solid piston; for if the pipe or lower opening be firmly closed after the piston has been drawn up so as to fill the barrel with air, it will be found impossible to thrust down the piston again completely while the pipe remains obstructed.



8. Let a tall narrow-mouthed glass jar or bottle be half filled with water A, and a funnel C, with a long tube, be inserted in the mouth of the bottle, as represented in the margin, and firmly secured at D, by luting or by passing it through a cork, in such a manner that the included air at B cannot escape between the funnel and the mouth of the bottle. Then water being poured into the funnel, little or none of it would pass into the bottle; for if the funnel had a tube several feet, or even yards in length, so as to give the advantage of strong hydrostatic pressure, though in that case the air at B would be compressed into somewhat smaller space, yet no imaginable force would fill the bottle, which of course would burst under a certain degree of pressure.

9. Another property of air is compressibility, in which it differs most essentially from liquids. It has been elsewhere stated that water undergoes no apparent diminution of bulk from pressure unless vast force is applied to it; and other liquids in different degrees resist compression, though readily dilated by heat and contracted by cold. But airs and gases, though, as we have just shown, manifestly endowed with impenetrability, yet display a facility of contraction and expansion under the influence of pressure, which is completely independent of temperature. They are, however, most powerfully affected by changes of temperature also; their bulk increasing or diminishing with the degree of heat to which they are exposed.

10. That the particles of air can be compressed, or driven by external force closer to each other than they were before that force was applied, must be apparent from the experiments adduced to prove the impenetrability of air; for while those experiments show that the particles of the compressed fluid cannot be destroyed, but will, when exposed to the utmost force, still occupy a certain space, yet it appears that contraction always takes place under the influence of pressure to a certain extent; and hence may be inferred another property of air already noticed, namely its porosity.

11. The compressibility of air may be experimentally illustrated by means of a strong glass tube closed at one end, like a barometer tube, and having fitted to it a piston, consisting of a strong iron wire or rod, with moisten d leather fixed to one end, so that it may move up and down in the tube quite air-tight. Then, the

How is air proved to possess the property of impenetrability?
In what manner is impenetrability manifested in filling a bottle with liquid?
How do gases differ from liquids in regard to compressibility?
How may the compressibility of air be experimentally illustrated?

tube being full of air, the piston is to be adapted to the open end, and if it be cautiously pressed down, the air may be reduced to about one-half of its original bulk, without using much force, and by stronger pressure the fluid may be yet further condensed, but at length the resistance will be such as to preclude the possibility of any greater compression.

12. The most remarkable among the properties of air is elasticity, depending on its expansive power, in consequence of which, when its dimensions have been reduced by pressure, it immediately recovers its bulk on the cessation of the compressing force. Thus, if the piston of a common syringe is pushed down while the air is prevented from escaping by the pipe, as soon as the pressure is withdrawn the piston will be raised by the expansion of the included air. To this property of air or gas is owing the force with which a pellet of wet paper is driven from a school-boy's popgun; and this insignificant little engine acts on the same principle with the air-gun and other philosophical instruments, which will be subsequently noticed.

13. Gravity or weight is another very important property of air, which it possesses in common with solids and liquids. Common air, as being comparatively lighter than water, will when set free below the surface of that liquid, rise through it, in the form of transparent bubbles. This is an effect of hydrostatic pressure, in consequence of which bodies of inferior specific gravity to water when immersed in it are pressed towards its surface; and thus it happens that a cork, a drop of olive oil, or a bubble of air or gas will float on the surface of water, and when forcibly pressed beneath it, rise again to the top as soon as the force that kept it down ceases to act.

14. The weight of air may be ascertained in the same manner as that of liquids or solids, by the common operation of weighing it with a balance. But in consequence of its extreme expansibility, some peculiar precautions are necessary in performing this operation, even when no great nicety is required. These, however, will be subsequently noticed; and it will be sufficient at present to state that by means of a large bottle with a stop-cock and a syringe adapted to it, the weight of a given quantity of air may be discovered. For suppose the stop-cock to be left open and the bottle weighed in that state, when of course it will be full of air, then the weight of the bottle and the included air having been noted, the air must be drawn out, as completely as possible, by screwing the syringe on to the stop-cock, and working the piston; the stop-cock is then to be turned so as to close the bottle, which on being weighed again, after being unscrewed from the syringe, will be found to have lost a portion of its weight equal to that of the quantity of air which it would hold.

What effect, resulting from elasticity, follows the compression of air?
What familiar facts illustrate this position?
What causes the rise of bubbles of air through a mass of liquid?
How is the *weight* of air demonstrated?

15. A cubic foot of air weighs about 523 grains; and consequently a cubic inch will weigh somewhat more than .3 of a grain, therefore if the bottle would hold three pints, its capacity, solid measure, would be rather more than 100 cubic inches, so that if it could be perfectly exhausted, it ought to weigh $.3 \times 100 = 30$ grains more when weighed with the stop-cock open, than it does after the air has been extracted from it. By using an air-pump instead of a syringe, a bottle with a stop-cock may be so nearly exhausted of air, as to leave behind no quantity sufficient to interfere in the slightest degree with the result of this experiment.

Different Kinds of Airs or Gases.

16. Common air, which forms the atmosphere surrounding on all sides the earth which we inhabit, was long supposed not only to be a simple elementary body, but even after its mechanical properties had been investigated, and great progress had been made in the study of the laws of nature, very erroneous ideas were retained concerning the composition of air, and it was imagined that all elastic fluids were essentially the same. It is now known that atmospheric air is a compound, consisting of two different species of air or gas, one of which, called oxygen gas, and sometimes vital air, is necessary to the support of animal life; and the other, named nitrogen or azotic gas, when inspired alone, is injurious to animals. Both these gases are capable of entering into combination with many other bodies of very different kinds, and producing compounds, some of which are usually in the solid or liquid state, and others in the form of permanent gases. There are likewise other gaseous bodies besides oxygen and nitrogen which have never been decomposed, and are therefore considered as simple forms of matter; and these, together with the various compound gases, constitute a very numerous class of bodies, which possess different degrees of elasticity and weight, and by their consequent pressure on solids and liquids, produce equilibrium or motion; and hence they are capable of being applied to various important purposes.

17. The peculiar nature and effects of the combinations of the gases with each other and with solid and liquid substances can only be ascertained by the application of the principles of chemical science; but the action of the gases or airs, so far as it depends

What is the weight of a cubic foot of air?

About how many grains less will a three-pint bottle weigh when exhausted than when filled with air?

What opinion prevailed among the early philosophers in regard to the nature of air?

How were all gaseous bodies regarded?

Of what materials is atmospheric air composed?

What analogy have oxygen and nitrogen with other gaseous bodies?

What differences exist in the mechanical properties of the gases?

How far does the examination of gaseous bodies belong to the science of pneumatics?

on their mechanical properties, forms the appropriate subject of Pneumatics.

18. Though atmospheric or common air, as being by far the most abundant and generally diffused of all elastic fluids, is therefore usually employed as the medium of pneumatic pressure, yet since the recent researches of men of science have made us acquainted with the variety of those fluids and their several properties, it appears that some of them may be adapted to the purposes of art with greater advantage than others, and atmospheric air is no longer the only kind of gas made use of as a moving power.

19. The discovery of elastic fluids much lighter than the atmo-* sphere has given origin to the art of Aërostation, or soaring through the air in an inflated balloon; the explosion of gunpowder, and the projectile force of balls, shells, and other missiles discharged from artillery, depends on the elasticity of a peculiar kind of air formed by the deflagration of nitre, sulphur and charcoal, composing gunpowder; and the combustion or burning together in close vessels of oxygen gas with another kind of gas called hydrogen forms water, which, being a liquid, nearly the whole space taken up by the gases previously to their combustion becomes a vacuum, and thus pressure may be produced, and a moving power obtained.

20. The application of the vapour of water to cause motion by the alternate expansion and condensation of steam affords an example of the advantageous adaptation of a non-permanent gas to the most important purposes; and if convenient means can be discovered for the liquefaction of common air and other gases by pressure and reduced temperature, as appears probable from the researches of Mr. Faraday and others, it may be expected that machines will be invented as far superior in some respects to the steam-engines now used, as *they* are to those which were constructed in the early part of the last century.

21. As the mechanical effects of the different gases when they act by pressure must depend on their relative specific gravities, it is of importance that those should be accurately ascertained. The following table will show the respective weights of equal quantities by measure of several elastic fluids, including those which are of the greatest importance, on account of their frequent occurrence and the valuable purposes to which they have been applied.

	Weight of 100 cubic inches.	Specific gravity.
Atmospheric air	30.5 grains	1.
Oxygen Gas	33.8	1.111
Nitrogen Gas	29.25	0.972
Nitrous Oxide	46.5	1.527

* To what mechanical purposes have the gases other than common air been applied?

By what species of force is motion impressed on projectiles?

How does the alternate formation and condensation of non-permanent vapour afford a mechanical agent?

How much do 100 cubic inches of common air weigh? How much the same bulk of oxygen? of nitrogen? nitrous oxide? hydrogen? car-

Hydrogen Gas	2.12	0.069
Carbonic Acid	46.5	1.529
Chlorine Gas	76.3	2.500
Subcarburetted Hydrogen Gas*	16.9	0.555
Carburetted Hydrogen Gas*	29.6	0.972
Steam	18.8	0.519

22. From this table it may be perceived that gaseous bodies differ greatly from each other in specific gravity; chlorine being 2½ times the weight of common air, and hydrogen only about 7-100 the weight of that fluid, so that common air is nearly 15 times the weight of hydrogen. Steam has but little more than half the weight of atmospheric air, and hence it rises through the air, in the same manner that a piece of deal or cork rises in water.

Elasticity of Air.

23. The most obvious and effective property of air is its elasticity, to which, with its gravity or weight, are to be attributed the phenomena of equilibrium, or motion in bodies under the influence of pneumatic pressure. In addition, therefore, to what has been already stated concerning these properties, a more detailed investigation of their nature and action will be requisite in order to the fuller elucidation of that branch of science now under our notice.

24. The elasticity of air appears from its resistance to pressure. The application of a heavy weight, or any external force to a woolpack or a bag filled with twisted horsehair would cause the pack or bag to give way, and become more or less contracted, but on the removal of the force it would expand to nearly its original dimensions.† What thus takes place is manifestly owing to the

bonic acid? chlorine? subcarburetted hydrogen? carburetted hydrogen? steam?

What substance is generally assumed as a standard of comparison in stating the specific gravities of the gases?

What are the several specific gravities of the gases compared with that substance as unity?

How many times heavier is common air than hydrogen gas?

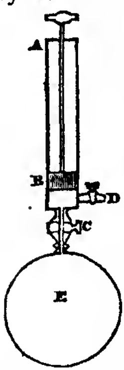
How much lighter is common steam than atmospheric air?

What property of air is most important in reference to its mechanical agency?

* The gases procured from the distillation of coal and from oil consist principally of subcarburetted hydrogen, or light inflammable air, and carburetted hydrogen, or heavy inflammable air. As these gases, which are now generally used for lighting streets and shops, are frequently mixed with other gases, the specific gravity must vary, in different specimens, with the degree of purity. Coal-gas, after it has been purified is found varying in specific gravity, from .450 to .700; while oil-gas, which contains a larger proportion of carburetted hydrogen, is much heavier, and therefore yields more light in proportion to its bulk.

† The manner in which elastic bodies act is strikingly illustrated by the novel application of spiral springs of iron wire in the construction of elastic chairs and beds. Dr. Paris, who notices this invention in his

form and texture of the included substances; the particles of which are separated by numerous interstices, and therefore readily yield to the force applied at the surface, which drives them nearer together without destroying their elasticity, or disposition to regain their previous situation, and hence they recede from each other, when the force which made them approach is withdrawn. A bladder filled with air may thus be compressed by squeezing it with the hands, and it will ewell out again as soon as it is relieved from the pressure, owing to its particles being endowed with a power of repulsion; for in proportion as they are left at liberty they exhibit a tendency to expand in every direction, so that their absolute dispersion through boundless space can only be prevented by the influence of pressure.

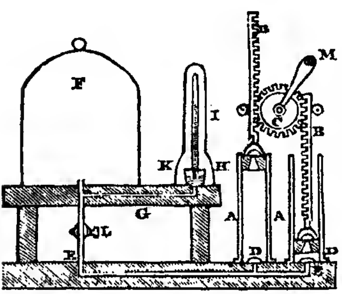


25. The elasticity of the air is most convincingly demonstrated by the operation of the machine called an air-pump, the construction of which is similar in principle to that of the syringe. By adapting two stop-cocks to a common syringe, and forming by means of them a communication with a vessel of convenient shape and dimensions, a rude and imperfect kind of air-pump might be contrived, by means of which air included in the vessel might be considerably rarefied or condensed. The effect thus produced will appear from the annexed figure, in which A B represents a syringe with a solid piston, C a cock, which when open, leaves a communication between the barrel of the syringe and the glass globe E; and D another cock which opens a communication with the external air. If now we suppose the piston to be at the bottom of the barrel, and the cock D shut, then on drawing the piston up to A, a part of the air in the globe will rush into the barrel, and the whole mass of the included air will become expanded; the cock C is then to be closed and the cock D opened, when the piston being pressed to the bottom of the barrel, the air it contained will be expelled through the open cock; this is next to be shut, and the cock C opened, and on drawing up the piston again, the air in the globe will become further rarefied; and these operations, the alternate opening and shutting of the cocks, and raising and depressing the piston, may be continued till a high degree of rarefication is produced. This apparatus is called an exhausting syringe.

Whence does this property become apparent?
What familiar illustration shows the nature of this action?
How is the dispersion of air through the regions of spaee prevented?
What machine demonstrates most satisfactorily the elasticity of air?
Explain the simplest form of this machine.

" Philosophy in Sport made Science in Earnest," says, " Down itself cannot be more gentle nor springy; and such beds never require to be shaken or made."

26. The same apparatus may be employed to effect the condensation of the inclosed air, by drawing up the piston with the cock C shut, and D open, and thrusting down with C open, and D shut; for by continuing this process, air would be made to enter by the cock D, and be afterwards forced into the globe E. The apparatus now takes the name of a condensing syringe; though valves which open and shut by the mere pressure and expansion of the included air are usually substituted for the stop-cocks. Valves are more convenient than stop-cocks, as requiring less labour and attention on the part of the operator; but a much higher degree of exhaustion can be effected by means of a syringe furnished with the latter than by using the common exhausting syringe with valves; yet these are generally adopted in the construction of exhausting and condensing syringes and air-pumps, as being much less expensive than stop-cocks, and more easily kept in proper order.



27. The air-pump, as might be inferred from its appellation, is a machine for extracting air out of a close vessel, and thus producing within it a degree of rarefaction nearly approaching to a vacuum; it being impossible, as we shall subsequently show, to form a perfect vacuum, by this or any other apparatus; though the exhaustion may be carried so far that the remaining air will not at all interfere with the results of our experiments.

28. The figure in the margin exhibits a section of an air-pump, from which it may be perceived that it essentially consists of two exhausting syringes, so arranged that they can be worked alternately. The syringes are marked A A, and their pistons are moved up and down within the barrels, by the racks or toothed rods B B, adapted to corresponding teeth on the periphery of the wheel C, having a winch or handle M, by which it may be turned so as to raise and depress either piston successively. Each of the pistons is furnished with a valve by which the air escapes as the piston descends, and there are other valves D D, at the bottom of each barrel, which become closed by either piston in its descent, but when it is drawn up, open a passage into the tube E E, communicating with the cavity of the glass bell F, called a re-

What purpose is served by the stop-cocks or valves of an exhausting syringe?

Is the air-pump adequate to produce perfect exhaustion within a containing vessel?

In what manner is motion usually communicated to the pistons of an air-pump?

ceiver. From the tube E passes off another tube G, the extremity of which opens into the bell-shaped tube K, within which is a small basin H, containing mercury, and the small tube I, closed at the upper end only, has its lower end plunged beneath the surface of the mercury. At L is a stop-cock, which when closed cuts off the communication between the receiver and the syringes, and which must therefore be opened while the machine is put in action. Another stop-cock, not shown in the figure, closes a passage through which the external air may be admitted under the receiver, when the result of an experiment has been ascertained.

29. There is so little difference in the mode of action of the air-pump and the exhausting syringe before described that the effect of the former will be readily understood. Either syringe in turn, by the elevation of its piston, and the consequent closure of the piston-valve and opening of the valve D, draws a portion of air from the receiver F, through the tube E E; and the alternate depression of each piston, by the elasticity of the air inclosed in the barrel, shuts the valve D, and prevents the air from returning into the receiver, at the same time that it opens the valve of the descending piston, and finds a passage into the upper part of the barrel, whence it is expelled by the piston in its next ascent. Thus, the reciprocal action of the syringes, by means of the rack-work, may be continued, till the requisite degree of rarefaction be produced in the air within the receiver. The only part of the apparatus requiring further explanation is the air-gauge, consisting of the tubes K and I, and the basin of mercury H, with which the latter tube is connected.

30. The air within the tube K, by its pressure on the surface of the mercury in the basin, will keep that portion of the same fluid in the tube I raised to a height exactly proportioned to the density of the included air, which must be the same with that in the receiver, in consequence of the communication by the tube G; and thus the height at which the mercury stands in the small tube I will serve as a gauge or measure of the elasticity and weight of the included air, being always in the inverse ratio of the rarefaction which has taken place.

31. It may be proper to add that the edge of the receiver must be ground perfectly smooth and level throughout its circumference that it may fit closely to the brass plate of the air-pump on which it rests; and that it may prevent the entrance of the air more effectually, it must be smeared with grease, or, as is more usual, set on a collar of oiled leather, and thus the junction of the receiver with the surface below it will be rendered impervious to the air.

What is the purpose of the mercurial apparatus connected with the air-pump?

What closes the lower valve of the pump on the descent of the piston within the barrel?

What ratio is preserved between the height of mercury in the gauge and the degree of rarefaction in the receiver?

What practical precautions are usually necessary to preserve the rarefaction obtained by the action of the air-pump?

32. A multitude of experiments, serving to demonstrate the elasticity as well as the weight of air, may be satisfactorily performed by means of this machine, which was originally invented by Otho Guericke, a German philosopher, in the latter part of the seventeenth century, and having been rendered more effective by the skill and science of Boyle and Hooke, it subsequently underwent numerous improvements, some of the most important of which we owe to the ingenuity of Smeaton, the celebrated engineer, of Dr. Prince of Salem, in Massachusetts, and Dr. Hare of Philadelphia.* But the principle and general plan of this philosophical instrument, under the various forms in which it has been constructed, correspond with the descriptive statement already laid before the reader.

33. The elastic force of atmospheric air may be rendered obvious by placing under the receiver of an air-pump a bladder, which has been about half filled with air and firmly tied at the neck so as to prevent it from escaping; for on exhausting the receiver gradually, the bladder will be seen to swell, from the expansion of the air within it; and if the exhaustion be continued long enough, the bladder will burst, from the elastic force of the air it contained, no longer counterbalanced by pressure on the external surface.

34. A square or flat glass phial, filled with air, well corked and fastened with wire, if placed under the receiver, will crack from the expansion of the air within it, as soon as the pressure is withdrawn from its surface by the exhaustion of the receiver. A phial of the usual shape would resist force applied internally or externally, much hetter than one with flat sides, in consequenee of its arched figure; hence the globular or hemispherical shape of the receiver, renders it best adapted for its purpose.

35. Shrivelled apples, prunes, or raisins, with their skins unbroken, when placed under a receiver, on the air being exhausted, will become plump from the elasticity of the air included in those fruits; and thus a bunch of dried raisins may be made to assume the appearance of a fine cluster of grapes, and a similar apparent renovation may be effected on the apples and prunes; but on readmitting the air into the receiver the fruits would all resume the wrinkles which betray their age.

36. If a large glass globe with an open mouth have a piece of

By whom and al what period was the air-pump invenled?

Who have contribuled lowards ils improvement?

How is lhe elasticily of the air proved by the experiment of the flaccid bladder?

What will occur when a lhin flat or square phial is placed under a receiver, and lhe air exhausted while lhe phial remains corked?

How may shrivelled fruil be temporarily reslored to a plump appearance?

Explain lhe experiment of the *glass globe and bladder*.

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* See Journal of the Franklin Institute, vol. xii. p. 303.

bladder tied over it, so securely that the air within it cannot escape while the bladder remains whole, and it be set under a receiver, while the air is being withdrawn from it, that within the globe will expand by its elastic force, and raise the bladder to a convex shape, distending it more and more as the exhaustion increases, till at length the bladder will be ruptured, and the air in the globe will expand itself through the receiver.

37. Let a small syringe, having a weight fastened to the handle of the piston be closed with a cork at the end, tied down with a piece of bladder, so that on pulling up the piston the air could not enter; then let it be suspended in an inverted position with the weight downward, under the receiver of an air-pump; upon extracting part of the air from the receiver, the weight at the handle will draw down the piston, and on readmitting the air the piston will rise again. In this case the partial exhaustion of the receiver lessens the elasticity of the included air so considerably that it is unable to support the weight; and on letting in the air again, it will recover its elastic force and raise the piston with the attached weight, in the same manner as it would be raised by the pressure of the external air.

38. A very amusing exhibition of the effect produced by the elasticity of the air may be made by means of the apparatus represented in the margin. Hollow glass figures, about an inch and a half in length, resembling men or women, must be procured, each having a hole in one foot, and the glass must be of such thickness that the figures will float near the surface of water when they are filled with common air. They are then to be immersed in a tall glass jar nearly filled with water, and covered on the top with a strong bladder, fastened air-tight. If the bladder now be pressed inwards with the finger, the water being almost *incompressible*, and the air quite the reverse, that contained in the little images will yield to the compressing force, and becoming contracted, water will enter, and the images thus becoming specifically heavier than they were at first will descend towards the bottom of the jar; on the pressure above being removed, the air in each image recovering its elastic force, will expel the water, and the images will rise as before. By forcing a little water into one or two of the figures before they are placed in the jar, they may easily be made to float at different heights; and thus their motions may be greatly varied, by regulating the pressure on the bladder. These diminutive images have been

How may the *syringe and weight* be made to exhibit the alternate expansion and contraction of air?

Describe the pneumatic toy called the bottle of imps.

In what manner may the *imps* be made to rise from the bottom of water, and how is the experiment to be explained?

whimsically called bottle-imps; and their agility must appear wonderful enough to those who are ignorant of the cause of it.*

39. The elasticity of the air may be further illustrated by placing an open jar containing a single glass figure, and filled with water, under the receiver of an air-pump, only the figure must be just heavy enough to sink to the bottom of the jar under the usual pressure of the atmosphere. Then on exhausting the receiver, and thus diminishing the elasticity and consequent pressure of the included air, the density of the water remaining the same, the figure will gradually rise, as the air becomes more rarified, till it reaches the surface of the water, where it will float, till the air is again admitted into the receiver, on which it will descend to the bottom of the jar.

40. Abundant proof of the compressibility and elasticity of the air may be drawn from the consideration of the mode of action of the common domestic utensil, a pair of bellows. This will at once appear on attending to the effect of the valve or leathern flap. This valve rises when the boards are separated, and the air enters through the hole in the lower board, which on pressing together the boards again becomes closed by the falling of the valve, and the air having no other vent, makes its exit through the pipe in a dense current.

41. The double bellows, used by blacksmiths and other artisans, differs from the machine just described in having an intermediate board, which is fixed, while the others are moveable, so that it consists of two air-chambers instead of one; and a hole in the middle board, with a valve, suffers the air which has boen drawn into the lower chamber through the hole below to pass into the upper chamber, where it becomes condensed by the pressure of a weight fixed to the upper board, and is discharged in a continued stream through a pipe connected with the upper chamber. The lower board is moveable, and when it sinks by its own weight, the valve opens, and shutting again when the board is raised by means of a lever or some other contrivance, the air is prevented from escaping by the valve-hole, and is therefore forced into the upper chamber.

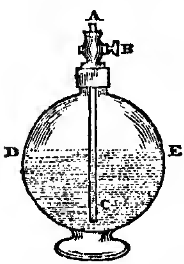
42. A kind of bellows or blowing machine, constructed entirely of wood, was invented at Bamberg in Bohemia about 1620, and was thence called the Bamberg bellows. It consists of two boxes, in the form of cylindrical sectors; one fitting into the other so as not to prevent it from being moved up and down, but without suf-

How is the common hand bellows constructed?
How is a constant stream of air maintained by the double bellows?
Of what does the Bamberg bellows consist?

* French writers on natural philosophy usually exhibit a single figure in describing the counterpart of this experiment. To this little enamelled figure, *petite figure d'email*, they give the name of *Ludion*.—V. Sigaud de la Fond Elem. de Phys., vol. iii. p. 162. Beudant Traite Elem. de Phys., p. 306.

fering the air to escape between the sides of the boxes. It is needless to describe it more fully, as the manner in which it acts may be easily conceived from what has been stated above. Various modifications of this machine have been adopted in establishments for smelting metals, and other purposes connected with the arts and manufactures.

43. The effect of air acting by its elastic force on the surface of water may be variously exhibited in the formation of *jets d'eau*, or spouting fountains. Let a strong decanter be filled to about half its height with water, and a glass tube of small bore be passed into it nearly to the bottom, and fixed air-tight, going through a hole drilled in a cork, with a piece of bladder tied over it and round the tube. This bottle is then to be placed under a tall receiver, on the plate of an air-pump; and on the receiver being exhausted, the air within the bottle will expand, and pressing on the surface of the water, cause it to issue from the top of the tube in a jet, the height of which will be proportioned to the degree of rarefaction of the air under the receiver.



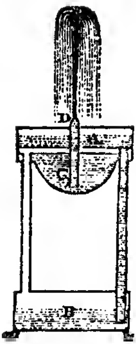
44. Compressed air may be made to produce a similar effect, which may be thus displayed: a strong bottle somewhat more than half filled with water, as represented in the marginal figure, by the line D E, must have a tube A C fitting into its neck, and capable of being opened or closed at pleasure, by turning the stop-cock B. A condensing syringe* being adapted to the tube at A, and the stop-cock opened, air is to be forced into the bottle, which rising through the water, will by its density press strongly on the surface of that liquid; then after turning the stop-cock the syringe is to be removed, and a small jet-pipe being fitted to the tube A, the stop-cock is to be opened, and the elasticity of the condensed air in the bottle will drive up the liquid in a jet, the height of which will gradually diminish, as the included air, by its expansion, approaches nearer and nearer to the density of the external air.

45. A small phial, with a well fitted cork, having a little tube or a stem of a tobacco-pipe passed through it, and reaching nearly to the bottom of the phial, partly filled with water, will, on blowing strongly into the bottle through the pipe, exhibit effects precisely analogous to those of the apparatus just described.

46. The machine called Hero's Fountain, resembles in principle those noticed above, differing from them only in the manner in which the compression and consequently increased elasticity of the air is produced. This is effected by means of a column

Explain the construction of the fountain in vacuo.
How is the force of air applied in the *compressed air fountain?*
In what respect does Hero's fountain differ from the preceding?

* See above, No. 26.



of water, as will appear from inspection of the annexed figure, representing one of the numerous forms in which such spouting fountains have been constructed. It consists of an open vessel A, from which a tube passes downward to the vessel B, from the opposite side of which another tube forms a communication with a close cavity over the basin C, having a jet-pipe extended almost to the bottom, and open above to the air. Water having been introduced into the basin C, more water is to be poured into the vessel A, till it runs down the tube, and fills the lower part of the vessel B, and compressing the air in it, and in the other tube and cavity above it, the water in the basin C, will, by the elastic force of the condensed air, be driven in a jet from the aperture at D; and by adding water to that in the vessel A, the enclosed air may be so compressed as to expel nearly all the water from the basin C. The principle on which Hero's Fountain acts has been heretofore adopted in Germany, in forming machines to raise water from mines; but they have been laid aside since the progress of science has led to the construction of far more powerful and efficient engines adapted to the same purpose.

47. A familiar example of the elastic pressure of the air occurs in the frothing of bottled ale, porter, cider, and the sparkling or creaming of champaigne wine, when uncorked and poured into an open vessel; the air which those liquors contain, on being released from its confinement in the bottle, escaping in numerous bubbles covering the surface of the liquor. Ginger beer contains a quantity of air or gas, formed by a chemical process, and such is its elastic force, that if the ginger beer has been properly prepared, the included air will drive out the cork with a loud report, as soon as the string with which it is tied down is cut through. Hence also the bursting of bottles filled with cider, perry, and other liquors considerably impregnated with air, when well corked and secured with wire.

48. What is called soda water is manufactured by compressing carbonic acid into water by mechanical means; and it therefore can scarcely be preserved except in strong bottles of a peculiar form, from which it spouts with violence through the elasticity of the condensed gas, as soon as the cork is removed. Air readily combines with water, though not to any great extent, under the usual pressure of the atmosphere. This will be evident on placing a glass of water under the receiver of an air-pump; for on exhausting the receiver the air will issue in a multitude of small bubbles from the surface of the water.

To what purposes has this fountain been applied in mining operations?
In what familiar operations is the elastic force of gaseous matter escaping from a liquid made conspicuous?
What is the nature of the preparation called *soda water?*

49. It has been already stated that a perfect vacuum cannot be obtained, even by means of an air-pump of the best construction. The impossibility of completely exhausting the receiver of an air-pump; so far as it is not owing to the imperfection of the machinery, depends on the identical property of the aërial fluid which causes the air-pump to act: for the elasticity of air is always in the direct ratio of its density; so that when half the air is extracted from any vessel, the remaining half will expand to fill the whole space, its density and elasticity being diminished in the same proportion. Thus if half the air could be exhausted from a receiver by the first stroke of the piston, and one-half of what was left by the next stroke, the quantity removed by every subsequent stroke must manifestly be but one-half of that removed by the stroke immediately preceding it: in fact, there must always be a remainder, however trifling it must at length become. It will be evident that though an indefinitely small quantity of air must thus remain after working an air-pump for any imaginable period of time, yet that quantity would soon become so extremely inconsiderable as to have nearly the effect of a complete vacuum.

50. Suppose the proportion of capacity between the barrel of an air-pump and the receiver to be such, that one-fourth part of the air would pass from the latter into the barrel at each stroke of its piston, then the quantity remaining in the receiver after the fifth stroke would be less than one-fourth of the original quantity; and as the decrease would go on in a geometrical progression, thirty strokes of the piston would leave in the receiver only 1-3096 of the quantity it contained at first. Hence it will appear that if the receiver be not less than the barrel, the smaller the difference between the size of the receiver and that of the barrel, the more rapidly must the rarefaction of the included air take place; and though with a small receiver the air may be highly rarefied in a short time, it cannot be entirely withdrawn.

51. It must also be observed that the extent to which the rarefaction can be effected will be limited by the operation of the rarefied air on the valves at the bottom of the barrels; for as the elasticity of the air remaining in the receiver is the cause of the opening of those valves, they will at length cease to act, when the exhaustion has been carried so far that the expanded air has not elastic force enough to overcome the very small degree of resistance caused by the weight and friction of the valves.

52. Another obstacle to the rarefaction beyond a certain limit will arise from the resistance to the opening of the piston-valves

Why cannot a perfect vacuum be obtained by means of the air-pump?

What would be the rate of exhaustion if the barrel had one half of the capacity of the receiver?

State some other relation between the bulks of the cylinder and receiver, and compute the degree of exhaustion after a certain number of operations.

What influence has the nature of the lower valve on the extent of rarefaction?

When must the rarefaction necessarily cease?

during the descending stroke, owing to the want of sufficient elasticity in the highly rarefied air to overcome the pressure of the atmosphere on those valves. Various improvements have been made in the construction of air-pumps, which have considerably lessened the imperfections in these machines now stated,* and though from the essential properties of air the formation of an absolute vacuum in the manner described must be impracticable, yet the ingenuity of modern artists has enabled us to produce within a receiver any degree of exhaustion requisite for the most delicate and interesting experiments.

Weight of the Air.

53. The phenomena depending on the influence of gravitation on air, and its consequent gravity or weight, are of equal importance with those arising from its elasticity; and the subject therefore demands a more extended investigation than has been already afforded to it.

54. Direct evidence of the weight or ponderosity of air may be easily obtained by means of an air-pump. For by ascertaining the weight of a bottle of known capacity before and after it has been exhausted of the air contained in it, the loss of weight after exhaustion would show the gravitating force of the air which had been extracted from it, and if the experiment be accurately performed it would appear that a cubic foot of air would weigh 523 grains. The same quantity by measure of water would weigh 1000 ounces avoirdupois; hence it must follow that water has about 840 times the weight of air, bulk for bulk; and this result corresponds sufficiently with the estimate of the specific gravity of atmospheric air compared with that of water, as stated in the table of specific gravities, in the treatise on Hydrostatics.†

55. As air then has a determinate weight like all other ponderable kinds of matter, it must produce pressure in the same manner as other heavy bodies, and that in proportion to its mass and specific gravity. The weight of 1000 cubic inches of atmospheric air must, from what is stated above, be greater than that of a single cubic inch of water, and consequently if the pressure of such a mass of air could be made to act on a small surface, it would produce a greater effect than the pressure of a cubic inch of

What other obstacle to rarefaction exists in the construction of the air-pump?

In what manner may the air-pump be employed to ascertain the weight of the air?

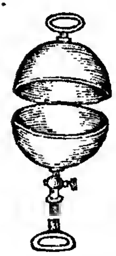
By what number of times does the weight of water exceed that of air?

* Such is the object of Dr. Prince's improvement, who makes use of a subsidiary piston to take off the pressure above the main pistons, after the exhaustion is nearly completed.—Ed.

† See *Hydrostatics*, No. 88.

water. Now the most direct mode of causing the pressure of a given bulk of air to act by its gravity on a surface of a certain extent would be, by forming a cylindrical or square column of air, the base of which should be exactly of the extent required. This could not be conveniently effected by artificial means, except in columns the height of which was but inconsiderable; but in the atmosphere around us nature presents a mass of air of great altitude, the vertical pressure of which on any given space may be ascertained by direct experiment.

56. A receiver, or any other air-tight vessel, placed on the plate of an air-pump, would become fixed to it by the exhaustion of the included air, in consequence of the atmospheric pressure on its surface. Some idea of the amount of this compressing force may be obtained by placing the palm of the hand over the top of a glass cylinder open at both ends, the lower opening resting on the plate of an air-pump, and the upper opening being covered by the hand so closely as to prevent the air from entering in that direction, the cylinder being partially exhausted the weight of the atmosphere pressing on the back of the hand would not only be sensibly felt, but would also be found to be so considerable before complete exhaustion had been effected, as soon to occasion pain and inconvenience. Reckoning the weight of the atmosphere upon every square inch of surface, to be fifteen pounds, the pressure on the hand placed over an exhausted receiver, the top of which it would just cover, would be equal to about sixty pounds.



57. A more exact estimate of the weight of the atmosphere may be formed by attending to the result of an experiment to show its effect on the surface of two hollow hemispheres, from which the air has been extracted by means of an air-pump or exhausting syringe. These hemispheres, constructed of brass, should be furnished with handles, or hooks, by means of which they may be suspended; one of which may be fixed, but the other should be removable. In the tubular neck to which this handle is screwed is a stop-cock, which being opened, and the handle removed, the hemisphere is to be screwed on the pump-plate, or on to an exhausting syringe; and the other hemisphere having been fitted to it, a vacuum is to be formed in the interior by working the pump. The stop-cock must then be turned so as to prevent the re-entrance of air, and on unscrewing the brass globe, and refixing the handle, it will be found that the hemispheres composing it are firmly united by the pressure of the external air. Suppose the diameter of the globe to

How might we conceive the pressure of a given bulk of air acting by its weight alone to be exercised?

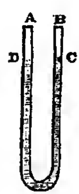
With what illustration of this subject does nature furnish us?

What causes the adhesion of an exhausted receiver to the plate of an air-pump?

How is the correctness of this explanation made apparent?

be 6 inches, the surface of a section through the centre would be about 28 inches square; and hence the pressure of the air upon one square inch being known, the force requisite to separate the hemispheres, supposing the exhaustion to be nearly complete, might easily be computed.

58. This is usually termed the Magdeburg experiment, it having been originally contrived by Otho Guericke, of Magdeburg the inventor of the air-pump; and it appears to have led him to that important discovery. For the manner in which he originally conducted the experiment was by filling the space included between the hemispheres, when pressed together, with water to expel the air, and then pumping out the water, while the air was prevented from re-entering by turning a stop-cock. Having thus ascertained the fact of the existence of atmospheric pressure to a great degree, he proceeded to the invention of the air-pump, by means of which the exhaustion of the joined hemispheres could be much more readily and conveniently effected than by the operose process he had at first adopted. This ingenious philosopher operated with two copper hemispheres, nearly a Magdeburg ell* in diameter; and the amount of pressure on such an extent of surface was so great, that when the interior cavity had been exhausted, the separation of the hemispheres could not be effected by the strength of twenty-four horses, twelve being harnessed together on each side, and dragging in opposite directions.



59. That the weight of the atmosphere is always proportioned to the vertical height of the column of air pressing on any extent of surface, may be demonstrated by means of a glass tube bent as represented in the margin, and open at both ends. The diameter of the tube being the same throughout, if mercury be poured into it, it will rise to the same height, D C, in either part of the tube. Then let the extremity, A, be closed by placing over it a piece of moistened bladder, firmly secured by melted resin or sealingwax; and the mercury pressed on by the air above it, of the common density of the atmosphere, would always remain at the same height, D; but the column of mercury in the other part of the tube having its surface exposed, would rise or sink with the variation in density of the atmosphere. Thus if such a tube were carried to the top of any high tower or mountain, the column of air would be shortened by a space equal to the height of the situation and the mercury, in some degree re-

Describe the manner of proving the pressure of air acting by its weight on the Magdeburg hemispheres.

How did Guericke at first produce the vacuum in his hemispheres?

What account is given of the size and efficacy of his apparatus?

In what manner can we prove what pressure the air exercises on the exterior surfaces of bodies?

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* See Winkler's Elements of Nat. Philosophy, Eng. Tr., 1757, vol. i. p. 131.

lieved from pressure, would rise in the space C B. On the contrary, if the tube could be removed into a deep mine, the mercury on the open side would sink below C, being pressed by a loftier column of air than when at the surface, where the height of the mercury was first noted.

60. Such an instrument as that just described would be a species of barometer,* since it would indicate the varying weight of the atmosphere. But the instrument to which the appellation of barometer has been given is differently constructed, and better adapted to afford a correct estimate of the amount of atmospheric pressure at different times, or under varying circumstances.

61. The invention of this valuable instrument appears to be justly attributed to Torricelli, professor of mathematics at Florence, in the earlier part of the seventeenth century. He was the pupil of the celebrated Galileo, who seems to have been the first among modern philosophers who had any idea that air possessed the property of weight; though he was not aware of the mode of its operation in producing atmospheric pressure, and the numerous phenomena constantly resulting from it.

62. It had been accidentally observed that in raising water by means of a pump, the height to which it could be drawn in what is called the suction-pipe never much exceeded 33 feet; since when the piston of a pump was elevated more than about that height above the surface of the water in the pump-well, the liquid no longer followed the piston. The drawing up of the piston of course forms a vacuum in the pipe below it, and the consequent rising of the water into the void space was accounted for, or rather attempted to be explained, by the philosophers of the sixteenth century, by the hypothetical principle that "Nature abhors a vacuum," and therefore causes the water to ascend in order to prevent the vacuum from taking place.

63. The dogma of Nature's abhorrence of a vacuum is a complete absurdity; and the phrase was invented, like many others, some of which are still current, to conceal the ignorance of those who pretended to universal knowledge. It was, however, generally adopted at the period just mentioned; and till it was discovered that, when a vacuum was actually formed in the suction-pipe of a pump, water would not rise to fill it much above 33 feet, no one seems to have thought of questioning the propriety of the current opinion on the subject.

What is the nature and purpose of the barometer?
Who was the inventor of that instrument?
Who first conceived the idea that air possesses weight?
By what expression did ancient philosophers explain the rising of water in a common pump?
In what light are we to view this expression?

* This term signifies a measure of weight, from the Greek Βαρος, a weight, and Μετρον, a measure. The instrument described in the text would bear a nearer relation to Adie's sympiezometer than to the common barometer.—Ed.

64. Some engineers at Florence finding themselves foiled in an attempt to raise water by a pump from a well of greater depth than usual, applied to Galileo for advice as to the means of raising water to a greater height than 33 feet, or at least for an explanation of the cause of a phenomenon which they could not reconcile with the generally received hypothesis concerning the ascent of water in the suction-pipe of a pump. Galileo is said to have told the inquirers that "Nature's abhorrence of a vacuum did not extend to distances greater than 33 feet, and therefore that at that point her efforts ceased." It has been questioned whether the philosopher really expressed himself in this manner, though the story has often been repeated; and it may at all events be concluded that if he gave such an answer to those who applied to him, he could hardly have considered it as a satisfactory solution of the difficulty which had been started. Accordingly in his writings he attempts to account for the phenomenon on other principles, but the real cause of it seems to have eluded his penetration.

65. Probably the discussions to which this circumstance gave rise suggested to Torricelli the idea that the ascent of water in the suction-pipe of a pump was caused solely by the pressure of the atmosphere on the water in the well, and that as the weight of the atmosphere at the earth's surface could never vary to any great extent, it therefore never greatly exceeded what would be sufficient to raise a column of water in a vacuum to the height of 33 feet. The happy thought occurred to him of verifying his conjecture by making an experiment with a fluid much heavier than water, as he perceived that if the ascent of water depended on atmospheric pressure, the same pressure on the heavier fluid would raise a column of it to a proportionally inferior height. With this view he fixed on mercury, as the heaviest fluid known, at common temperatures; and having procured a glass tube, open at one end, he filled it with mercury, the specific gravity of which compared with that of water was as $13\frac{1}{2}$ to 1; then immersing the open end of the tube in a small jar of mercury, and suffering a communication to take place between the mercury in the tube and that in the jar, he observed that the fluid sunk till it stood in the tube just 30 inches above the level of that in the jar below. This experiment was so far completely satisfactory; for as $13\frac{1}{2} : 1 :: 33$ feet : $2\frac{1}{2}$ feet = 30 inches; thus the weight of the atmosphere pressing on any given surface was found to be equal to that of a column of water of the same extent at the base and 33 feet in height, or of a similar column of mercury only 30 inches in height.

What is said to have been the reply of Galileo to inquiries on this subject?

Did that philosopher understand the true cause of the rise of fluids into an exhausted tube?

To whom do we owe the true explanation of this subject?

In what manner did Torricelli demonstrate the correctness of his views in regard to the pressure of the air?

66. The barometer now in general use as a weather-glass is nothing more than a tube of proper length filled with mercury, and either dipped at the open end in a small cup of the same fluid, or else having the open end curved upwards, so that the mercury may be exposed to the pressure of the atmosphere: a scale of inches also is adapted to the upper part of the tube, extending from 27 to 32 inches, that it may appear by inspection at what height the mercury stands under the pressure of the atmosphere at any particular time. This useful instrument was at first called the Torricellian tube, from the name of the discoverer of the principle on which its action depends; but it subsequently received the designation of a barometer, now universally adopted.

67. After the effect of atmospheric weight and consequent pressure had been ascertained by the decisive experiments of Torricelli, the subject was further investigated in France, chiefly by the distinguished philosopher Pascal, and by Father Mersenne, in 1647. The former reflecting on the effects of atmospheric pressure, it occurred to him that the weight of the column of air, depending on its vertical height, must be greatest in low situations, and decrease in ascending an eminence. To try this principle by the test of experiment, he requested a friend who resided in Auvergne, to ascertain the relative heights of a barometrical column at the bottom, and afterwards at the top of the Puy de Dome, a high mountain, situated in that province of France. The effect took place as Pascal had anticipated; and he himself subsequently made corresponding observations on a barometer, removed from the level of the street in Paris to the summit of a lofty church-tower.

68. As a philosophical instrument, the barometer is highly useful, not only for the purpose of ascertaining the daily and hourly variations which are taking place in the atmosphere in any given situation, arising from causes connected with the science of meteorology, and for other purposes of a similar nature; but likewise as affording means for accurately estimating the heights of mountains, or in fact of any places whatever above the level of the sea. For either of these purposes, however, it is necessary that a barometer should be very carefully and accurately constructed; and in making observations by means of it, especially in the measurement of heights, various precautions are required, and the effect of temperature in particular must be taken into the account in making any calculations.

69. It must hence be obvious, that as a weather glass, the utility of such instruments as are commonly used must be extremely

Describe the manner of constructing the barometer.
By what name was this instrument formerly known?
What application of the barometer was made by Pascal?
In what manner was his principle verified?
To what particular purposes is the barometer applied in meteorology?
What particularly requires attention in the measurement of heights by the barometer?

limited; for as the height of the mercury at any time must depend partly on the elevation of the place of observation above the level of the sea, no correct judgment can be formed relative to the density of the atmosphere, as affecting the state of the weather without reference to the situation of the instrument at the time of making the observation; and a series of observations at any given place would be required in order to enable a person to form a probable opinion of the change of weather to be expected after the rising or falling of the mercury.

70. One source of imperfection in the instrument, which renders it difficult to determine the extent of those slight variations in the height of the mercurial column which are yet interesting to the meteorological observer, has led to some peculiarities of construction, by means of which the scale of observation might be enlarged, and minute changes in the height of the mercury be rendered obvious. One method of effecting this purpose is by means of what is called a wheel barometer, the external appearance of which few persons can be unacquainted with, as such instruments are generally preferred for domestic use.

70. The construction of the wheel-barometer may be thus described, with reference to the figure in the margin. It consists of a tube, A B C, hermetically sealed at A, and open at C; and of such a length that the distance from C to A may be about 32 inches. The tube must be entirely filled with mercury, which on placing it in a vertical position will subside in the part A B, till the difference of the levels E and F will be equal to the height of a column of mercury which will balance the weight of the atmosphere, so that any change of pressure will have an equal effect on the mercury at E and F, and thus through whatever space the fluid may rise at E, it will be depressed to the same extent at F. Upon the surface of the mercury at F floats a small ball of iron, suspended by a strong thread over a pulley P, and to the other end of the thread is attached the weight W, not so heavy as the floating ball. The axis of the pulley passes through the centre of a large graduated circle G, and carries an index H, which revolves as the pulley turns round. The weight W being just heavy enough to counterbalance the iron ball and overcome the friction of the pulley, the iron ball rises and falls freely, as the surface of the mercury on which it floats is elevated or depressed by the weight of the air. Now if the circumference of the wheel P be 2 inches, then one entire revolution will corre-

Why is the barometer, as commonly constructed, ill adapted to the purposes of indicating the state of weather?

How has it been found practicable to enlarge the scale of barometric variations, so as to read slight differences?

Give a description of the wheel-barometer.

What is the purpose of the weight suspended on the exterior end of the cord?

spond to an alteration of level amounting to 2 inches at F, and therefore to an alteration of 4 inches in the height of the barometric column. And as the graduated circle may conveniently be 40 inches in circumference, 10 inches of that circle will correspond to 1 inch of the column, and 1 inch of the circle to 1-10 of an inch of the column; so that variations, amounting to much less than the tenth of an inch will be distinctly perceptible.

72. As already stated, the utility of the barometer as a weather-glass must depend on certain circumstances, with reference to the situation of the observer; and not the least attention ought to be paid to the words "rain," "fair," "changeable," &c., frequently engraved on the plate of a barometer, as they will be found to afford no certain indications of the correspondence between the heights marked and the state of the weather.

73. General rules for calculating changes in the weather from the barometer can seldom be adapted to all situations; and therefore those who may be desirous of obtaining the means for forming a correct judgment, as to subsequent alterations in the state of the atmosphere, from the indications of the degree of atmospheric pressure at any time afforded by the barometer, must devote much attention to the subject; without which, written rules would only mislead the observer, and long application to the practical study of the instrument would render rules unnecessary. One circumstance, however, may he worth mentioning, which is, that changes of weather are indicated not so much by the actual height of the barometrical column, as by its variation of height, and the manner in which that variation takes place.

74. Among the methods which have been adopted to obtain the most accurate estimates of the effect of atmospheric pressure may be noticed the compound barometer, in which water is added to the mercury in the tube, and the mean height of the barometrical column being thus augmented, the variations which arise from the varying weight of the air will be more considerable than in a common barometer, and therefore may be more distinctly observed. Such instruments, however, are liable to certain defects and disadvantages, which render them inferior upon the whole to those of the usual construction.

75. A barometrical column, composed of water alone, from its extreme sensibility to changes of atmospheric pressure, must afford much greater facility for noticing the more minute alterations which are found to be constantly occurring than the mercurial barometer. But a water barometer must necessarily be a most unwieldy machine, and consequently could be adopted in but few situations, even where the expense and inconvenience attending its construction might be of little importance.

What reliance is to be placed on the prognostics of weather sometimes found on the scales of barometers?

What circumstance, in regard to changes of weather, deserves particular attention? What advantage is possessed by the column composed of water and mercury?

76. M. Pascal, whose philosophical researches have been already noticed, made some interesting experiments at Rouen, in Normandy, in which he, by means of glass tubes, 40 feet in length, ascertained the effect of the pressure of the atmosphere on water, and also on wine; and he found that when mercury stood in the common barometer at the height of 2 French feet 3½ inches, water was raised in one of his tubes to the height of about 31 1-9 feet, and wine to that of 31⅗. Thus, though the difference of specific gravity in these two liquids must have been but inconsiderable, yet it occasioned a sensible difference in the manner in which they were affected by atmospheric pressure. The experiment on water was repeated by Roger Cotes, professor of philosophy at Cambridge, England, in the beginning of the last century; but in both cases the object was merely that of a temporary exhibition for the purpose of distinctly demonstrating the operation of aërial gravity and pressure.

77. A permanent water-barometer, however, has been erected by order of the Royal Society of London, in the hall of entrance to their apartments, the tube extending upwards in the well of a winding staircase. It consists of a glass tube 40 feet in length, and 1 inch in diameter at the lower end, nearly cylindrical throughout, being only a little narrower at the upper extremity than it is below. This instrument is well adapted to show the various periodical alterations, or as they have been termed, oscillations of the atmospherical column, and some observations, with tables formed from them, have already been laid before the Royal Society, by Mr. Daniell. It has been noticed, that the rise and fall of the column of water in this barometer precedes, by one hour, the corresponding changes in a mercurial barometer; and it is stated that in windy weather the water is in perpetual motion, its fluctuations in the tube having been compared to the breathing of an animal.*

78. It has been already observed, that the elasticity of the air is always in the direct ratio of its density; or in other words, that the greater the density of any portion of air, the greater will be the degree of elastic force which it is capable of exerting. The best modern air-pumps are so constructed as to serve for the condensation as well as the rarefaction of air; but for the former purpose, a condensing syringe may likewise be employed; and either method may be adopted in making experiments on the elasticity of compressed air.

79. Among the most interesting applications of the force of air

What relation did Pascal find between the heights of columns of wine and of water equivalent to the weight of the atmosphere?

In what peculiar manner is the water barometer found to be affected?

What advantage does it possess over the *mercurial barometer*, in regard to the indication of diurnal fluctuations?

In what ways may the artificial condensation of air be effected?

* Arcana of Science, 1833, pp. 263, 264.

in a state of high condensation is that of projecting by such means bullets or other missiles from an air gun. It is somewhat remarkable, that this instrument appears to have been in use before the discovery of the air-pump or the barometer; for it is mentioned in a work entitled "Elémens d'Artillerie," written by David Rivaut, who was preceptor to Lonis XIII. of France, and he ascribes the invention to Marin of Lisieux, in Normandy, who presented an air-gun to Henry IV. It is also stated, that an air-gun was preserved in the armory of Schmettau, on which was the date 1474. But these instruments were far inferior to modern air-guns, from which they must have differed considerably in the mode of construction.

80. The air-gun, like the common gun or musket, consists partly of a long metal tube adapted to receive a ball, but the breech end of the tube or barrel has an opening to admit condensed air behind the ball, which, acting by its elastic force, propels it with a velocity, proportioned to the degree of condensation of the air. Though the effect is produced in the manner just described in all air guns, yet the mechanism or arrangement by which the admission of the air is regulated varies in different instruments. Some of them are furnished with a syringe for compressing the air, included within the butt of the gun, and there is an exterior tube surrounding the barrel, so that the air is forced into the space between the tubes, and the ball having been introduced into the barrel which it fits closely, a valve is opened by pressing on a knob or trigger, and the air rushes from the cavity formed by the outer tube into the chamber behind the ball, which it expels from the barrel, continuing to act upon it by its expansive force till the ball has passed from the mouth of the air-gun. Other instruments have but one tube, for the reception of the ball; and the air is compressed by a condensing syringe into a strong brass or copper globe, which when filled, can be detached from the syringe, and screwed to the butt of the gun, and by a contrivance similar to that already described, a bullet can be discharged, by drawing a trigger. The butt may be made to hold a magazine of balls, which can be admitted one at a time into the chamber, and a portion of the condensed air escaping on opening the valve, several balls may be projected from the air-gun in succession, but in this case, as each discharge will diminish the density and elasticity of the remaining air, the velocity and effective force of the balls will also progressively decrease.

81. From what has been stated relative to the density and elasticity of air, it will follow, that all bodies on the surface of the

What are some of the important applications of condensation?
What are the essential parts of the air-gun?
To what is the velocity of the ball proportioned?
What two different arrangements of parts are occasionally applied for retaining the condensed air?
Can this instrument propel, with equal velocities, several balls in succession, without renewing the charge of air?

earth, sustain a pressure from the superincumbent atmosphere equal to the weight of a column of water, about 34 feet in height, with a base corresponding in extent to that of the body or bodies pressed upon. This pressure may be estimated at from 14 to 15 pounds on every square inch of surface, being the weight of a column of mercury 30 inches high, and 1 inch square at the base.

82. Hence it must be evident that every human being constantly has pressing on the body in every direction a weight equal to 15 times as many pounds as there are square inches on the surface of that body. Suppose then the surface of a man's body to measure 2000 square inches, the force of the atmosphere pressing on that surface would be equal to 30,000 pounds. It may appear unaccountable that so vast a pressure should be perpetually in operation, without our being sensible of the weight or experiencing any inconvenience from it. This however is owing to the uniform manner in which the force acts in all directions, so that the body is supported by the pressure on one side against the equal pressure on that which is opposite; and it is only when the equilibrium is destroyed by removing the force in one direction, that its effects become perceptible, as is shown by an experiment previously described, in which the hand is exposed to atmospheric pressure by placing it over a partially exhausted receiver. All the cavities of the body also are either filled with air or with denser fluids, so that they resist compression from the external air as perfectly as the firmest solids.

83. Some idea of the weight of the whole atmosphere, encompassing the earth on every side, may be formed from a calculation which has been made to determine what must be the diameter of a sphere of lead, the weight of which would be equal to that of the entire atmosphere; and from which it appears that the sphere must have a diameter nearly 60 miles in length; which would correspond in weight with a mass of water sufficient to cover the whole surface of the earth to the height of 34 feet.

84. It is an interesting matter of speculation to what height the atmosphere extends from the surface of the earth. If the density of the atmospheric column were uniform, its vertical height might be readily calculated; for as water is nearly 850 times heavier than air of the common density, and a column of water 34 feet high is equivalent to an atmospherical column having a base of the same extent, it is evident that the height of such a column of air of uniform density must be 850 times 34 feet, or $850 \times 34 = 28,900$

What amount of atmospheric pressure is sustained by all bodies on the surface of the earth?

What pressure is applied to the body of a person of ordinary size?

How is the body enabled to sustain this pressure without inconvenience?

What would be the diameter of a sphere of lead equal in weight to the whole atmosphere of our globe?

To how thick a stratum of water over the whole globe would this be equivalent?

How may we calculate the height of an atmosphere of uniform density equal in weight to that of the earth?

=5 miles 833 yards and 1 foot, or nearly $5\frac{1}{2}$ miles. But the density of the air varies at different distances from the surface of the earth, in consequence of its elasticity.

85. Air may be conceived to consist of innumerable strata or layers, forming a concentric shell, surrounding the solid globe we inhabit; and the lowest stratum being compressed by the whole weight of the superincumbent mass, must necessarily be more dense than the next above it, and the density decreasing in proportion to the increase of height or distance from the earth's surface, no definite limit can be assigned to the extent of the atmosphere.

86. Cotes, in his Hydrostatical Lectures, has stated the relative density of the atmosphere at different heights, as deduced from a comparison of the specific gravity of air at the common level of the earth's surface with that of air at a certain elevation as ascertained by means of the barometer. Thus the rarity of the air being four times greater at the altitude of seven miles than at the surface, and the rarity of the air augmenting in a geometrical progression, while the altitude increases in an arithmetical progression, it will follow that at the height of 14 miles the atmosphere would be 16 times rarer than at the surface, at 21 miles 64 times rarer, at 28 miles 256 times, at 35 miles 1024 times, at 70 miles about a million of times, at 210 miles a million of millions of millions of times, supposing air to be capable of indefinite expansion. Hence, also, at the altitude of 500 miles, if the air could continue to expand at the same rate, a cubic inch of the common density would be dilated through a greater space than a sphere equal in diameter to the orbit of Saturn.* This, however, is a purely hypothetical estimate, for it is founded on the presumed infinite divisibility of matter.

87. The observations of Dr. Wollaston, "On the Finite Extent of the Atmosphere,"† tend to prove that air consists of ultimate indivisible particles; and the expansion of a medium composed of such particles must cease at a certain point where the force of gravity acting downwards, upon a single particle, would be equal to the resistance arising from the elastic or repulsive force of the medium. At such an altitude, therefore, the elasticity of the atmosphere would be completely extinguished, and thus a physi-

How may we conceive the atmosphere to be arranged upon the surface of the globe?

What limit can be assigned to the height of the atmosphere?

State the calculated progressive rarefication of air as dependent on elevation.

On what supposed property of air is this calculation founded?

What views did Dr. Wollaston advance on this subject?

What equality of forces would limit the expansion of air?

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* See Cotes's Hydrostatical and Pneumatical Lectures. Sec. edit. Cambridge, 1747, p. 124.

† Abstracts of Papers in the Philos. Trans., vol. li. pp. 160—162.

cal limit might be assigned beyond which it could not possibly extend.

88. In making calculations relative to the density of the air at different heights, or forming rules for the determination of the correspondence between atmospheric altitude and pressure, for practical purposes, such as the measuring of eminences by means of the barometer, several circumstances must be taken into the account. Thus it is not only necessary that the exact height of the mercurial column at different levels should be ascertained, but due regard must also be had to the influence of temperature, the effect of vapour suspended in the air, and the latitude of the eminence whose height is to be determined. The indefatigable spirit of research of modern experimental philosophers and mathematicians has triumphed over these difficulties so far as to have furnished us with general principles and formulæ, by the application of which to the results of carefully conducted experiments, the perpendicular heights of the principal mountains in every part of the world have been discovered.

89. From calculations founded on the barometical formula contrived by the celebrated mathematician, Laplace, and adapted to the estimation of heights, it appears that at the elevation of 52,986 metres, French measure, or 173,795 English feet,* the rarity of the air as equal to the utmost degree of rarefaction which can be obtained in the exhausted receiver of an air-pump. This manifestly connot be the extreme altitude of the atmospheric column, nor is it possible to decide that point with certainty. But it appears from the observations of astronomers on the duration of twilight and the magnitude of the shadow of the earth by which the moon is eclipsed, that the rays of light from the sun are affected by the medium through which they pass at the distance of from 40 to 50 miles from the earth's surface;† and therefore it may be reasonably inferred that the atmosphere extends to the altitude of at least 45 miles above the level of the sea.

90. The pressure of the air arising from the joint effect of elasticity and weight is the cause of a great number of phenomena constantly taking place around us, and immediately depending on the operations of nature or art. It is thus that the effect of the instrument called a sucker, used by schoolboys, is to be explained. It consists of a disk of moistened leather, with a string by which it may be suspended with any weight attached to it

What three circumstances are to be taken into account in measuring heights by barometric observations?

At what height has Laplace calculated that air will have as great a rarity as it is possible to produce by the air-pump?

What height of our atmosphere is deduced from the observations of astronomers on the duration of twilight, and the magnitude of shadows in eclipses of the moon?

* A French metre is 39.37 inches English measure, or 3.28 feet.

† See Treatise on *Optics*.

and as its smooth moist surface may be pressed so closely against the flat side of a stone or other body, that the air cannot enter between them, the weight of the atmosphere, pressing on the upper surface of the leather, makes it adhere so strongly that a stone of weight proportioned to the extent of the disk of leather may be raised by lifting the string. If the sucker could act with full effect, a disk an inch square would support the weight of 14 pounds; but the practical effect of the instrument must be variable, even supposing that it was accurately constructed.

91. Whenever surfaces are brought into such close contact that the air cannot insinuate itself between them, they will be pressed together with a force corresponding to the extent of the surface of contact. Hence glass-grinders and polishers of marble find that the substances on which they are operating by friction, when reduced to a state of extreme smoothness, become united by atmosperic pressure so firmly that great exertion is required to separate them, and the circumstance is the cause of considerable inconvenience.

92. The adhesion of snails, periwinkles, limpets, and some other crustaceous animals, to rocks and stones, is effected on the same principle. The surfaces of their shells at the opening are capable of being exactly fitted to any plane surface; these animals have the power of producing a vacuum within their shells when thus fixed, and the atmosphere consequently presses on them with a force proportioned to the extent of exterior surface. It is thus, too, that a common house-fly is enabled to run with great facility up a perpendicular pane of glass, or on the under side of a horizontal plane, as the ceiling of a room. The feet of the insect are provided with cavities, the sides of which being adapted to the surface of glass, &c., by some internal mechanism the cavities are exhausted, and the pressure of the atmosphere on the minute surface of the feet supports the insect against the power of gravitation. That such small animals may be thus sustained will probably appear less extraordinary than that a similar power of running up a perpendicular plane should be possessed by a much larger creature.

93. But Sir Everard Home, who, by means of microscopical observations explained the structure of the fly's foot, as connected with its mode of progression on walls and windows, also investigated the anatomy of the foot of tho lacerta gecko, a kind of lizard, found in the island of Java, which walks up and down the smoothly-polished walls of the Javanese houses, pursuing the flies on which it feeds, and it runs upwards to its retreat in the

How is atmospheric pressure illustrated in the stone-sucker?

What facts do marble masons experience connected with the same principle?

What facts in natural history prove the application of atmospheric pressure to the position and locomotion of animals?

What enables flies and other insects to walk upon upright surfaces and ceilings?

How are the feet of the gecko formed?

roofs of houses, though its weight is sometimes 5¼ ounces. It has on each foot five toes, and on the under side of each of these are sixteen transverse slits, with serrated edges, and pouches between them, by means of which the animal is enabled to form a vacuum within the cavities, produoed by the application of the loose membranes, surrounding the under surface of the toes, to a wall or any other smooth plane.* Nature has provided animals of far superior bulk to this lizard with a similar organization, and for the same purpose.

94. Sir E. Home, from an examination of a specimen of the amphibious marine animal, called by naturalists the walrus, from the Arctic regions, discovered that there is an analogy in structure between the hind foot of the walrus and the foot of the fly; so that this large clumsily-shaped animal is enabled to proceed upon the smooth surface of ice against gravity, by the adhesion of the feet, owing to atmospheric pressure.†

95. Those who are but slightly acquainted with natural history can hardly be ignorant of the faculty belonging to the fish called remora, which fixes itself firmly to the side of a ship or to that of a larger fish, as a shark; and thus it travels without the exertion of swimming from one part of the ocean to another. It has a sort of sucker on its head, by the application of which it becomes attached, the pressure of the surrounding water having the same effect in this case as that of the air in those previously noticed.

96. Among the experiments which have been devised to demonstrate the elastic pressure and weight of the atmosphere, the following are well adapted to the purpose.

I.

97. Take a quart bottle and drill several holes in the bottom, then set it in a wide-mouthed jug, and having filled it quite full of water, cork it securely. On lifting it from the jug it will be found to hold water notwithstanding the perforations, the pressure of the atmosphere preventing its escape; as will appear on taking out the cork, when the water, being equally pressed above and below, will run out through the holes till the bottle is emptied.

II.

95. A wine-glass filled with water may be held with the mouth downwards without spilling a drop. The means by which this seemingly marvellous effect is produced are extremely simple. It

What advantage does the walrus enjoy in consequence of the peculiar structure of its feet?

By what apparatus is the remora enabled to adhere to the sides of a vessel or those of a larger fish?

In what manner may a vessel, the bottom of which is perforated, be still made to hold water?

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* See Abstracts of Papers in Philos. Trans. from 1800 to 1830, vol. ii. p. 38.

† Idem, p. 213.

is merely necessary to place a piece of paper on the surface of the water with which it must be every where in contact, and also with the rim of the glass, which is then to be inverted; and as the air cannot get in to act on the liquid above, its pressure is exerted against the under surface alone.

III.

99. A tumbler or goblet may be filled with water, and the surface being covered as before with paper, which may be held up with the palm of the hand, while it is suddenly inverted, then placing it on the surface of a smooth table, the paper is to be withdrawn, and the water will remain suspended in the glass; which will adhere closely to the table from the pressure of the atmosphere. Any one may now be safely challenged to lift the glass vertically without spilling every drop of the water; for it would require some exertion to move the glass at all upwards, and as soon as it was elevated on one side, the included water would sink down and escape.

100. It is in consequence of the unrestrained pressure of the atmosphere that liquor will not flow from a cask after it has been tapped or pierced, unless another opening be made as a vent-hole in the upper part of the cask: for till this is done the force of the air pressing on the mouth of the tap, having nothing to counterbalance it, would support a column of liquor, if the cask was air-tight, the height of which would be proportioned to the specific gravity of the liquor. When, however, the air is enabled to act through the vent-hole above, the pressure below is counterbalanced, and the liquor descends and runs through the tap by the effect of its own weight. The operation of the same principle may be observed in using a tea-pot; for there is always a small hole in the lid through which the air enters, and without which the liquid would not flow from the spout, if the lid fitted close, as it ought.

101. Many circumstances of frequent occurrence may be traced to the influence of atmospheric pressure acting irregularly. The stoppage of a supply of water from wells and fountains during a frost is sometimes owing to this cause; for the frost does not extend far beneath the surface of the earth, but it consolidates it so as to prevent the access of air to the channels of water from which fountains and wells are fed, and thus the atmosphere pressing only on the open well prevents the water from entering it as usual, till a thaw takes place, and the ground again becoming pervious to the air, it acts on the feeding springs, and the water rises in the well.

How is the paradox of the inverted glass of water to be explained?

How may a full goblet be inverted upon a table without spilling its contents?

How is atmospheric pressure concerned in the discharge of liquid from a cask, urn, or other close vessel?

In what manner can you account for the occasional failure of springs in severely cold weather?

102. The instrument, called in French Tâte-liqueur, or Chantepleur, and that used in filling essence-bottles, act on the principle of atmospheric pressure. Their construction and effect will be readily apprehended from inspection of the annexed figure, which represents a small conical tube, A B, open at both ends; and when in this state the lower orifice is plunged beneath the surface of any liquid, a portion of it will enter at A, and fill that part of the tube A C, which is immersed in the liquid; if then the upper extremity B be closed air-tight by placing the thumb over it, the tube may be lifted out of the liquid, and the pressure of the air below will prevent it from escaping, till the thumb is removed, and the air thus allowed to act on the surface of the liquid at C. The length of the tube to raise water in this manner might obviously be extended to more than 30 feet; as the height of the liquid column which the atmosphere would keep suspended would be greater or less according to its specific gravity. Such instruments of a moderate length are conveniently applicable to the purpose of withdrawing a small quantity of any liquor through the bung-hole of a cask.

103. The Siphon* affords another illustration of the principle under discussion. It is employed for the purpose of decanting or drawing off liquors, and is variously constructed. If an open tube of small diameter, bent into the shape of the letter U, be filled with water, and the curved side turned upward, the liquid will be suspended by the pressure of the air on the open extremities, while the tube is held in such a position that the columns of liquid in both legs shall be exactly of the same height; but if the tube be inclined at one side more than the other, so as to destroy the equilibrium, the water will run down and escape through that end which is at the lowest level. So if a common siphon, or bent tube with one side longer than the other be filled with water, and inverted or held with the open ends downward, the atmospheric pressure acting equally on both sides, and the liquid columns being unequal, the water will escape through the longest leg, falling in virtue of its own specific gravity. But if, when such a siphon is filled, its shortest leg be plunged beneath the surface of water, not only will the liquid all run out of the longest leg, but it will also rise in the shorter, and be discharged from the other in a continued stream, till it sinks below the open end of the shorter leg.

101. If the siphon be used without previously filling it with

How may we apply the pressure of air to the purpose of raising small quantities of liquor from a cask?

To what length might a tube for this purpose be extended?

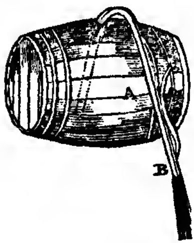
What is the construction and use of the siphon?

What principle besides that of atmospheric pressure is concerned in producing the continued action of the siphon?

Why will not the siphon act without previously filling both legs of the tube?

* From the Greek Σιφων, a tube.

the liquid to be decanted, though the liquid will rise in the shorter leg, it will not ascend beyond its own level, so as to pass over the bend of the tube, and escape, unless the air be drawn out of the longer leg. Hence the utility of that kind of siphon represented in the margin, the peculiarity of which entirely consists in



the addition of the tube C, open at the upper end, and communicating below with the longer leg of the siphon B. The shorter leg A then being plunged into the bunghole of a cask, or into any other vessel containing liquor, the opening B is to be stopped with the hand, or otherwise, and by suction at C, the liquor may be made to pass over the bend and fill the leg B, when being suffered to escape, it continues to flow, as long as the extremity A is immersed in it. Large siphons of this sort, made of copper, and furnished with a stop-cock, just above the opening B, may often be seen in action; being used by the distillers and liquor-merchants to draw off spirits.

105. The Wirtemberg Siphon, shown in the following figure, when once filled with liquid, will remain so, and hence may be hung up in that state ready for use. One leg A being plunged into a vessel of the liquid to be drawn off, it will escape through

the open extremity B, in consequence of the additional pressure of the liquid in the vessel at A; thus it will appear that this siphon acts somewhat differently from those of the common construction, though it is applicable to similar purposes.

106. Tantalus's Cup, or the Magical Goblet, is an amusing philosophical toy, which consists of a cup with a cavity at the sides or bottom, or both, with which the longer leg of a siphon communicates; so that when water is poured into the cup high enough to overcome the pressure of the air on the end opening into the cavity, the liquid will sink in the cup, and run into the cavity; and thus it can never rise so high as the mouth of the figure within which the siphon is concealed; and the classical fable of Tantalus is realized. There must be an aperture near the rim of the cup to admit air into the cavity, or rather to suffer it to escape, and by closing it with the finger, the cup may be filled to the brim; but as soon as it is unclosed the water will sink as before. If a hollow handle, communicating with the lateral cavity, be fitted to the cup, the hole may be so placed at the inner side of the handle as to escape notice; and the effect will appear astonishing to those unacquainted with the theory of atmospheric pressure.

To what practical purpose is the siphon frequently applied?
What advantage is possessed by the Wirtemberg siphon?
In what manner is the cup of Tantalus constructed?

107. Intermitting fountains, or periodical springs, are found in some places, and from the capricious and apparently unaccountable irregularity of such streams they have been regarded as miraculous, in dark ages, and have given rise to abundance of superstitions among the common people. There is a remarkable spring of this kind called Laywell, near Torbay, in Devonshire, England, and the peculiarity of this and other intermitting fountains, may be satisfactorily shown to arise from the operation of siphons formed by nature, communicating with subterraneous reservoirs.*

108. The siphon may be made available for the purpose of conveying water over the side of a pond or reservoir into another, provided the latter is on the same or a lower level than the former. It was thus very ingeniously applied by a French engineer, M. Garipuy, in 1776, to discharge the surplus quantity of water from the canal of Languedoc, when it had been raised above the proper level by the influx of water at the mouth of the river Garonne during a storm.

109. Whenever water is conveyed by pipes from a higher to a lower level, over an intervening eminence, the principle on which the siphon acts must be adopted; and thus water may be made to pass over any height not much exceeding 30 feet. It is thus conducted from Lochend to Leith, near Edinburgh, through pipes, the intermediate ground being 8 or 10 feet above the fountain head. It is necessary that the water should be driven in the first instance beyond the most elevated part of the pipe by a forcing-pump, and it then continues to flow by the influence of atmospheric pressure. But as air, always loosely combined with flowing water, will be gradually extricated from it at the bend or highest part of the pipe, it will at length there accumulate so as to stop the flux of the water. When this happens, the forcing-pump must be worked to renew the current.

110. From what has been stated with regard to the siphon, it follows that it can only be used for transferring liquids from higher to lower levels; therefore when water or any other liquid is to be raised by means of atmospheric pressure, some kind of pump must be employed. Pumps are variously constructed. The marginal figure below, (111,) represents the common suction pump, which is nothing more than a syringe so contrived that the water

With what natural phenomena are the principles of the siphon connected?

From what source do intermitting springs derive their supply of water?

For what hydraulic operations may the siphon be employed?

How high may water be made to pass over a barrier?

In what manner is the siphon trunk for such purposes usually filled?

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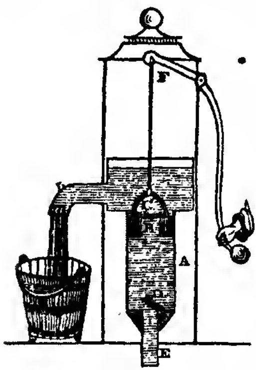
* For an account of Laywell, see Philos. Trans., No. 424; see also Nos. 119, 189, 192, and 384. There is an interesting paper on the noted intermitting Spring at Giggleswick, in Yorkshire, by Mr. Gough, of Kendal, in Nicholson's Journal of Natural Philosophy, 8vo.

drawn into it passes through the piston by means of a valve, and is discharged above it, instead of being again forced out below The invention of this instrument is attributed by Vitruvius to Ctesibius or Ctesebes, an Athenian engineer, who lived at Alexandria, in Egypt, about the middle of the second century before the Christian era; and the construction of syringes, fire-engines, and other machines acting on similar principles is described by his scholar Hero, in a treatise on Pneumatics, still extant.



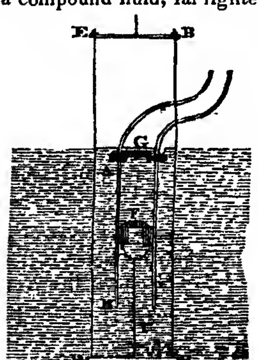
111. The suction-pump consists of two hollow cylindric pipes A and E, the latter of which usually terminates below in a perforated ball, through which the water in the well enters freely into the suction-pipe; and at its other extremity is a valve D, opening upwards, and affording a communication, when open, with the upper pipe A. In this pipe, constituting the barrel or body of the pump, the piston B moves air-tight vertically, and by its valve C opening upwards, it permits the water to pass above it and be discharged at the spout. Now suppose the piston to be at the bottom of the barrel in contact with the valve D, on lifting the former by depressing the lever handle of the pump, connected with the piston-rod at F, the valve C will be closed by the pressure of the air above, and a vacuum being thus formed in the barrel, the same pressure on the surface of the water in the well, will drive it up the suction-pipe, and raising the valve D, the water will enter the exhausted barrel, whence by depressing the piston, the valve D will be shut, and that at B rising, the water will pass upwards and be discharged through the spout. The first effect of working such a pump must be to form a partial vacuum in the barrel of the pump, and the upper part of the pipe E, and it will be only after the whole of the included air has been expelled through the piston-valve, and replaced by water in the pipes, that the liquid begins to flow, the atmospheric pressure below taking full effect, while the equivalent pressure above is counteracted by the manual force applied to the handle of the pump.

112. The suction-pump cannot raise water beyond the extent of action of atmospheric pressure, the utmost limit of which will be about 34 feet; so that the height of the valve D above the level

Describe the construction and operation of the common pump.
To whom is its invention attributed?
By whom were syringes and fire-engines first described?
What closes the upper valve of the suction pump before it has become immersed in water?
What is the first operation which takes place within the barrel of the pump?

of the water in the well must never exceed that distance; and unless the pump be accurately constructed, so that the piston in its descent fits close to the bottom of the barrel, so as to form a perfect vacuum in its ascent, the water will not rise to the extreme height in the suction-pump. It must appear somewhat paradoxical, that though this will be the effect when the pump is in the best working order, the valves and pipes being air-tight, yet a pump, the suction-pipe of which has been damaged, so that a small quantity of air can enter, will raise water nearly as high again as a good pump.

113. A tinman of Seville, in Spain, ignorant of the principles of science, undertook to construct a suction-pump to raise water from a well 60 feet deep: when the machine was finished, he was confounded at discovering that it had no power to raise water at all, and enraged at his disappointment, while some one was working the pump he struck the suction-pipe with a hammer or axe, so forcibly as to crack it, when to his surprise and delight the water almost immediately began to flow, and he found that he had thus attained his purpose. This happened about 1766, when M. Lecat, a celebrated surgeon, then at Rouen, in Normandy, being informed of it, made a similar experiment on a pump in his garden, by boring a small hole in the suction-pipe, 10 feet above the level of the water in the cistern, and having adapted to it a stop-cock, he found that when it was open the water could be discharged at the height of 55 feet, instead of from 30 to 34 as before.* The circumstance admits of an obvious explanation, the effect being analogous to that exhibited by *jets-d'eau*, when air is mingled with the acending column of liquid.† Thus in the case of the pump, the air presses in through the slit or aperture in the suction-pipe, and becoming mixed with the water in its ascent, forms a compound fluid, far lighter than water alone, and therefore acted upon by atmospheric pressure more readily, and thus it produces the phenomenon described. However, as there are other and more efficacious methods of raising water to great heights, the contrivance just noticed is not to be recommended.

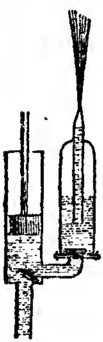


114. The Lifting-pump, as represented in the margin, acts in much the same manner as the preceding, but the machinery is reversed. It consists of a hollow cylinder or barrel A B, in which is fixed the valve G, a little below the level of the water in the well or reservoir. A piston F with a valve opening upwards, fits into the lower part of the barrel, in

* V. Sigaud de la Fond Elem. de Phys., t. iii. pp. 238, 239.
† See *Hydraulics*, No. 11.

which it is moved vertically by means of the frame B C D E, connected with the piston-rod I. Now when the piston is at the bottom of the barrel, the pressure of the atmosphere on the surface of the water in the well will open the piston valve; and the water will rise to the same height within the barrel as without; and on lifting the piston, its valve F will close, and the water above it will be driven by the opening of the valve G, into the upper part of the barrel: then the piston being depressed again, the valve F will open to admit more water into the lower part of the barrel, while that above will be prevented from returning by the closing of the valve G; and thus by continued working of the piston, the water will rise in the barrel till it escapes by the spout.

115. In both the suction-pump and the lifting-pump, the water will be discharged by jets, unless a kind of reservoir is made by the enlargement of the barrel above the spout, in which case it may be made to flow in a continuous stream.



116. The forcing-pump is another form of this useful machine, combining in a great degree the properties of those already described. It is composed of a hollow cylinder, the lower end of which dips into the water in the well; just above the valve, in the upper part of this cylinder, a lateral pipe branches off, having at a short distance from its origin another valve, both valves opening upwards; and in the upper part of the cylinder or barrel is a solid piston or plunger, moving air-tight vertically. Now if the piston be depressed to the lower valve, and then raised, that will open, while the valve in the lateral pipe remains closed, and the pressure of the atmosphere on the water in the well will cause it to rise a little and expel a part of the air through the first valve; the piston then being lowered that valve will close, and the air above it be expelled through the other valve; thus every elevation of the piston will make the water rise higher in the cylinder till it has expelled all the air, and it will consequently, at the next lifting of the piston, pass above the first valve, and the piston being again lowered, as the liquid cannot descend, the valve being closed, it will be forced into the lateral pipe, through its valve, and as it is prevented from returning again by that valve,

What is the greatest height to which water may be drawn up by a well constructed pump of this form?

In what manner was it discovered that a mixture of air and water may, by the action of a pump, be raised higher than 34 feet?

How is this action explained?

Of what does the lifting-pump consist?

Is the lifting-pump limited to any particular height to which it can raise the liquid column?

In what manner is a constant stream maintained either in the lifting or the suction-pump?

Describe the form and action of the forcing-pump.

Which of the preceding pumps constitutes a part of this?

it will continue to ascend with every down-stroke of the piston, and may thus he raised to any height required

117. In a pump of this kind, the stream will be intermitting, unless there be a cistern above the spout, to form a head of water which may act by hydrostatic pressure; or the same object may be more effectually attained by closing the force-pipe, so that a portion of condensed air may press on the surface of the water after it has passed the valve, and an open tube, fitting air-tight, entering the chamber, and having its lower extremity, plunged beneath the surface of the water, that liquid will be driven up it by the pressure of the included air, and form a *jet-d'eau*, or flow in a regular stream, according to the disposition of the spout or mouthpiece.

118. The fire-engine is a modification of the forcing-pump, consisting essentially of two working barrels, like an air-pump, but fitted with solid pistons, and valves corresponding with those of the forcing-pump; and thus water is drawn from any reservoir or other source of supply, and propelled into a strong air-chamber, from the upper part of which passes a tube, having its inferior extremity dipped under the surface of the water, which is thus driven through it by the pressure of the condensed air. The tube just mentioned may be connected with the part that enters the air-chamber by a universal joint, and thus its extremity may be conveniently turned to throw water in any direction; or as more usual, it may have fitted to it a flexihle leathern pipe or hose, by means of which the stream may he conducted to any spot where it may be made to act with the greatest effect.

AEROSTATICS.

119. The laws which regulate the ascent and descent of floating bodies have been generally elucidated in treating of specific gravity, as connected with the science of Hydrostatics. It was there demonstrated that liquids differing in density when placed in contact would assume an arrangement depending on their relative weights or densities, the heaviest always sinking to the bottom of the containing vessel, and the others floating at heights corresponding to those weights.* Solids, immersed in liquids, in the same manner either sink or float according as they may be heavier or lighter than the medium in which they are placed. Thus if a vessel were partly filled with mercury, and water standing above

What device maintains a constant efflux in the forcing-pump?
What are the essential parts of the fire-engine?
What device enables the fireman to direct the stream in any direction, according to circumstances?

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* See *Hydrostatics*, No. 76.

it, then on dropping into it a piece of iron, the solid metal would be seen to fall through the upper stratum of the liquid mass, and stop at the surface of the lower stratum, as consisting of a metallic fluid more dense than the solid metal.

120. An analogous effect might be exhibited with gases of different densities. If a quantity of carbonic acid or fixed air were to be poured into a large glass jar, so as to fill the lower half of it, the upper part of the jar would be occupied by atmospheric air, as the lighter of the two fluids; and any bodies of specific gravity intermediate to these gases, as soap bubbles, being let loose over the jar would fall through the upper stratum of gas, and be arrested by the lower, on the surface of which they would float, just as a cork would float on water.

121. A great number of substances of various kinds are suspended in the atmosphere within a moderate distance from the surface of the earth; some of them, in consequence of their extreme minuteness, belonging to the class so picturesquely described by Shakspeare as "the motes that people the sunbeam." These floating corpuscules appear to be numerous in proportion to the heat of the air; and hence they are much less frequent in winter than in summer.

122. "We are ignorant of the precise nature of this fine powder. Perhaps it may be a mixture of inert matter extremely divided, with the exquisitely small germs of various species of organized bodies, as the eggs of insects, the seeds of plants, and likewise the fecundating powder from the stamens of flowers. It is in fact known from the observations of naturalists, that under many circumstances, animalcules and minute vegetables of different species become developed, though it is impossible to perceive the germs from which they are derived. It is certain, also, that flowers furnished with pistils only, (as those of the date palm,) are fecundated, and bear fruit, though the plants furnished with stamens are found at considerable distances, and even separated from the others by vast tracts of sea. All these observations tend to confirm the hypothesis of the transmission of germs and fecundating powders by means of the atmosphere. Indeed we take nature in the fact, as it were. under many circumstances; thus plumose or tufted seeds are frequently observed flying in the air, as those of the lettuce, the dandelion, and others, with which children sometimes amuse themselves. And it may be perceived that the seeds of many species of vegetables are furnished with delicate membranes or wings; as, for instance, those of the fir

What analogy exists between the phenomena of liquids and those of gases, when different kinds are poured into the same vessel?

Give examples of that analogy.

In what manner is the floating dust of the atmosphere seen in warm sunny weather to be accounted for?

Is the ascension of those substances from the earth rendered probable by any known facts in natural history?

What seems to be the design of the thin membranes and delicate gossamer with which the seeds of certain plants are furnished?

the elm, &c., which seem formed expressly in order that the wind may raise them, so that they may be transported in all directions, and thus contribute to the propagation of the species to which they belong.

123. "Relatively to the fecundating powders, it may be remarked, that in forests of pines and firs, at the period of flowering, the ground is covered for several days with an extremely fine light powder, which becomes raised in the air by the winds in prodigious quantities, and conveyed to distant places, where the descending clouds have been often mistaken for showers of sulphur. Also during the season of the flowering of wheat, the fecundating dust, or pollen, may be seen floating over the fields like a thick mist."*

124. The modern art of aërostation, or as it has been more correctly styled aëronautics, depends on the application of the principle of specific gravity to the action of gases on solid bodies, and the consequent motion of the latter through the atmosphere. After the invention of the air-pump, when the mechanical properties of the air had been experimentally demonstrated, the feasibility of contriving a machine for the purpose of navigating the atmospheric regions became a favourite subject of speculation among men of science.

125. Bishop Wilkins, a distinguished mathematician, and one of the earliest members of the Royal Society of London, was so far convinced that a method of travelling through the air might be discovered, that he hazarded the opinion that the time would come when a man about to take a journey would call for his wings as familiarly as he might now for his boots. But the idea of taking advantage of the principle of specific gravity to form a flying-engine, that should rise in consequence of its being lighter than an equal bulk of air, appears to have been first published, if not conceived, by Francis Lana, an ingenious Jesuit. The scheme he proposed was that of attaching to a car four hollow globes of copper, which were to be exhausted by means of an air-pump; and which he imagined would have sufficient ascending power to elevate the car and the aëronautic adventurer. It seems to have been merely a theoretical project, which must have failed in the attempt to execute it; for neither globes of copper nor any other substance known could be manufactured in such a manner as to be at once buoyant, from the thinness of the sides, and strong enough to resist atmospheric pressure.

What remarkable appearance is often exhibited by the surface of the earth in the flowering season of pines, firs, &c.?

How early, and by what occurrences, were men induced to attempt aërial navigation?

What appears to have been the earliest conception of this subject, and how did it differ from the idea of Lana?

Why was the project of the latter impracticable?

* Beudant Traite Elem. de Physique, pp. 334, 335.

126. Nearly a century had elapsed after the publication of the abortive plan just noticed, when the discovery of hydrogen gas, or inflammable air, by Cavendish, about 1766, and of its remarkable inferiority of density compared with common air, revived the speculations of philosophers on the subject of aëronautics. Dr. Black, of Edinburgh, soon after ascertained, by experiment, that a thin bladder filled with hydrogen gas would rise to the ceiling of a lofty room, and remain suspended till it was taken down; and several years subsequently the subject was further investigated by Cavallo, a Portuguese gentleman, residing in England, who was a fellow of the Royal Society.

127. It was, however, in France that the invention of the air-balloon took place. Two brothers, Joseph and Stephen Montgolfier, paper-makers, at Annonay, constructed a large square bag of fine silk, and caused it to ascend in an inclosed chamber, and afterwards in the open air, by heating the air within it by means of burning paper. After several preliminary experiments, a balloon was constructed at Paris, consisting of an elliptical bag, 74 feet in length, and 48 in breadth, with an aperture below, near which was suspended an iron grate for burning wood and straw, and a boat or car attached for the reception of aërial travellers; and in this machine the first ascent was made, in October, 1783, by Pilatre de Rozier, superintendent of the Royal Museum. Other experiments of the same kind followed, with balloons rendered buoyant by the admission of heated air.

128. But this method of aërostation was liable to inconveniences and imperfections, which rendered it less eligible than that of employing balloons inflated with hydrogen gas, the chief objection to which arose from the expense attending it. This, however, was obviated by means of a public subscription; and December 1, 1783, M. Charles, professor of natural philosophy, at Paris, and his companion M. Robert, ascended from the gardens of the Tuilleries, by means of a balloon filled with hydrogen or inflammable air. The success of this undertaking demonstrated the superiority of this mode of construction; and it was consequently adopted by many other experimentalists, both in France and elsewhere. Lunardi, an Italian, was the first aëronaut who exhibited in England; and among those who distinguished themselves by their enterprising spirit, or philosophical researches, amidst the fields of air, may be noticed the names of Blanchard, Garnerin, Zambeccari, Dr. Jeffries, W. Windham Sadler, and Gay-Lussac, the last-mentioned of whom, in 1804, ascended from

How long was Lana's scheme published before the discovery of hydrogen gas?

What experiment by Dr. Black is probably the earliest form of balloon ascension?

In what manner did the Montgolfiers effect the elevation of their silk bag?

What is related of the form and size of the first balloon with which an aëronautic expedition was made by Rozier?

Why was not hydrogen adopted by the earliest aëronauts?

Who were among that number?

Paris, furnished with instruments for making meteorological observations; and from the descent of the mercury in his barometer, he inferred that he had, when at his utmost elevation, attained the height of about 23,000 feet above the level of Paris; and this appears to be the greatest distance from the surface of the earth to which any person has hitherto risen by means of an air-balloon.

129. Several accidents have occurred to aëronauts in the prosecutions of their adventures, and some have lost their lives; as Pilatre de Rozier, who, after repeated successful ascents, was killed, together with M. Romain, in consequence of the balloon taking fire in which they had attempted to pass from France to England, in June, 1785; Madame Blanchard, the wife of the aëronaut, mentioned above; and W. W. Sadler, who, after having made thirty atmospheric voyages, in one of which he crossed the Irish Channel, was precipitated from his balloon, owing to the car striking against a chimney, at the height of about forty yards from the earth. Notwithstanding these and other fatal disasters, aëronautic expeditions have been so frequently undertaken, that most persons must have had opportunities for witnessing them; but though several useful purposes to which air-balloons might be applied have been suggested, the difficulty of managing them has hitherto prevented their adoption except as objects of display.

130. The air-balloon consists of a light bag of thin silk, of a globular or elliptic shape, and rendered air-tight by a coating of varnish, made by dissolving gum-elastic in spirits of turpentine. When thus prepared, it must be distended with some elastic fluid, lighter than common air; and it will thence acquire an ascending power equal to the difference between its weight, including the attached car and its contents, and that of the bulk of atmospheric air which it displaces. Suppose the diameter of the silk globe to be 20 feet, its circumference will be about 63 feet, its superficial measure about 1257 square feet, and its contents, solid measure, 4190 cubic feet; then if it be filled with gas having only ¼ of the specific gravity of common air, and admitting that a cubic foot of the latter would weigh 1½ oz., and that 1 square foot of taffeta or thin silk would weigh 1 oz.:—

The weight of atmospheric air displaced will be	6285 oz.
The weight of gas in the balloon - - - -	1571¼
The weight of the taffeta - - - - -	1257
	2828¼
	3456¾

To what height did Gay-Lussac ascend?

To what purpose have balloons been hitherto applied?

Of what does the air-balloon consist?

What would be the ascensional force of an unloaded balloon of silk 20 feet in diameter filled with hydrogen of a specific gravity ¼ that of common air? Calculate on similar principles the force of a balloon 30 feet n diameter?

131. Hence the inflated balloon would weigh 3456 oz., or 216 pounds less than an equal bulk of common air; and therefore such a balloon, with a car and its contents attached, weighing 200 pounds, would have an ascending force equal to 16 pounds. But if it were filled with pure hydrogen gas, having a specific gravity but 1-13 that of common air, its power of ascension would manifestly be augmented in a high degree.

132. Aëronauts in general were accustomed to use inflammable air, procured by dissolving pieces of iron or zinc in sulphuric acid diluted with water; a tedious, troublesome, and inconvenient operation, which was never found to produce gas approaching to the specific gravity just mentioned. Hence Mr. Green, who has distinguished himself by the number of his aërial expeditions, amounting to about one hundred, determined to make a trial of coal gas. From some preliminary experiments he ascertained that the ascending force of a balloon three feet in diameter, when inflated with gas from coal, was equal to 11 oz.; and that when filled with hydrogen gas procured in the usual way, its force was not more than 15 oz. He therefore, in his ascents in the neighbourhood of London, availed himself of the convenience of procuring gas from the coal-gas companies, which he found to be sufficiently adapted for his purpose.

133. The accidents which occurred to some of the earlier aëronauts suggested the idea of contriving a method of descending independent of the balloon, if circumstances should render it desirable. The first experiments for this purpose were made by Le Normand, in 1783; and Blanchard subsequently constructed a machine resembling a large expanded umbrella, called a parachute, which he let fall from a height of 6000 feet above the earth, with a dog in a basket suspended from it. A whirlwind arrested its descent and swept it above the clouds; but it soon approached the balloon again, when the dog recognized his master, showing his uneasiness and alarm by barking; another current of air then carried him out of sight, and he ultimately landed in safety, though not till after the descent of the balloon. Garnerin, who used a parachute 25 feet in diameter, with a basket attached to it, descended from the air by this means, several times, both in France and in England; and on one occasion from the perpendicular elevation of 8000 feet.

134. On the principle of the parachute depends the buoyancy of numerous light bodies presenting an extended surface to the air; and thus a little canopy made by attaching four strings to the angles of a sheet of paper with a light weight in the place of a car, if dropped from an eminence will descend but slowly to the ground.

What has recently been substituted for hydrogen in the inflation of balloons?

What relative ascensional forces will be given to balloons by coal-gas and hydrogen respectively?

What is the form and what the object of the parachute?

What accounts are given of the use of this apparatus?

Some experiments founded on the observation of such facts, made in Germany, may here be noticed. Zacharia of Rosleben, conceiving the possibility of forming a flying boat, constructed, by way of trial, a case of light wood covered with linen, in the shape of a flat obtuse-angled keel, 5½ feet in diameter, and ½ a foot deep, weighing 14½ pounds. On the 17th of September, 1822, this machine was launched from a scaffold on the race-course of Wendelstein, the scaffold being 27 feet high, and standing on a rock 100 feet above the surrounding plain; so that the perpendicular height was 127 feet; and the boat flew to the distance of 153 feet. A second flying boat 7¼ feet in diameter, ½ a foot deep, and 25 pounds in weight, which was launched from the scaffold on the same day, took a somewhat more elevated path, and landed after a flight of 158 feet. These experiments appear to have been expensive, and the result was not sufficiently flattering to induce the projector to repeat them.*

135. Attempts have been made at different periods to construct wings for active flight through the air; but they have all proved abortive. The celebrated historian, William of Malmesbury, in his account of the conquest of England by the Normans, mentions an alleged prediction of that event, by Elmer, or Oliver, a Benedictine monk of Malmesbury, in consequence of the appearance of a comet, in 1060. This monk appears to have been a learned and ingenious man, who was skilled in mathematics. But his claim to notice at present is grounded on his being the earliest English aëronaut on record; though his speculation was not only unsuccessful but unfortunate. For the historian informs us that Elmer, having affixed wings to his hands and his feet, ascended a lofty tower, whence he took his flight, and was borne upon the air for the space of a furlong; but owing to the violence of the wind or his own mismanagement through fright, he fell to the ground, and broke both his legs.†

136. The famous Roger Bacon, who died towards the end of the thirteenth century, in his treatise on the Secret Works of Nature and Art, expressly asserts the possibility of constructing machines in which a man sitting might move through the air, by means of wings, like a bird flying.‡ In the fifteenth century,

What success has attended the various attempts which have been made to employ aërial boats?

How early do attempts of this kind appear to have engaged the serious attention of speculative men?

What success attended the flights of Elmer, Dante, and Degen?

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* Elements of Natural Philosophy. By Prof. Vieth, of Anhalt-Dessau, (German.) Leipsic, 1823. p. 208.

† Gul. Malmesbur. de Gestis Regum Anglorum, lib. ii. cap. 13.

‡ "Possunt etiam fieri instrumenta volandi ut homo, sedens in medio instrumenti, revolvens aliquod ingenium, per quod alæ artificialiter compositæ aërem verberent, ad modum avis volantis."—Epistola Fratris R. Baconis de Secretis Operibus Naturæ et Artis. Hamburg. 1572. p. 37.

John Baptist Dante, a mathematician of Perugia in Italy, excited the astonishment of his contemporaries by his aëronautic exploits. But his career was unfortunate; for we are told that after he had repeatedly crossed the lake of Thrasymene through the air, he took his flight from an eminence in his native city, when his machinery becoming deranged, he fell on the roof of a church, and fractured his thigh. The Journal des Sçavans, December 12, 1678, contains a description of a flying-engine contrived by a locksmith of Sablé, in the county of Maine, in France, by means of which the inventor descended from a second floor window, and proposed to fly from a height over a river. Professor Vieth says, that the latest experiments on the art of flying were made by a watchmaker at Vienna, named Degen; but they seem to have led to no practical results of importance.*

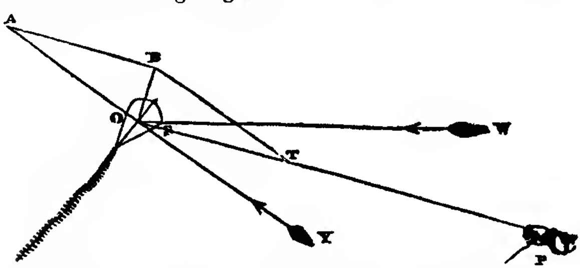
137. The ascent of sky-rockets affords an interesting object of philosophical speculation, and the phenomenon has been variously accounted for by men of science. The rocket consists of a cylindrical case or cartouch of thick paper filled with a composition of gunpowder, charcoal, steel filings, and other inflammable matter; with a head technically styled "the pot," at the upper extremity; and a light stick, to which the rocket is affixed laterally. Its flight, like that of other projectiles, depends on the sudden expansion of compressed air, formed by combustion. The cause of the ascent of the rocket is, that whereas it would, if it were not for the aperture below, be equally pressed on all sides within by the expanding gas, and would remain at rest, but this pressure, like that of steam in a boiler, will often on a small portion of its inner surface greatly exceed the weight of the containing vessel. In such cases, the opening of an aperture sufficiently large, will project the container in the direction *opposite* to that in which the opening takes place. It will be perceived that from this account of the effect, the operation would be the same in vacuo as in the open air. In fact the effect is no more due to the impinging of the escaping gas against the air below, as Dr. Hutton and others have supposed, than the effect of effluent water in Barker's mill is to be attributed to the same cause. Several steam-boilers which have exploded in the United States have gone off through the air like rockets, having first formed a rent in such a part as to allow the issuing steam to urge the enormous mass forward by its elastic action. One occurrence of this kind at Pittsburg was, at the time, described as having been accompanied by a train of light; as if the issuing stream had been an inflammable mixture. A revolving

Of what does the sky-rocket consist?
On what does its flight depend?
What causes the rocket to ascend when the contents are inflamed?
What analogous effects on a larger scale have sometimes been witnessed?
By what method is the rapid developement of gases obtained in the rocket?

* Elem. of Nat. Philos., p. 209.

apparatus, like a Barker's mill, only adapted to the action of air instead of water, may be set in motion by condensed air; but will revolve with rather more velocity if placed in the receiver of an air-pump, and, after exhaustion, set in motion by allowing the external air to find an entrance through the revolving arms. Dr. Hutton justly remarks that the rocket would not rise unless the elastic fluid were produced in abundance; and hence the necessity for piercing in the centre of the rocket a conical hole, and thus the composition when inflamed burns in concentric strata, of much greater extent than the circular disk to which the combustion must otherwise be confined, and the expansive gas is formed in quantities sufficient to produce the required effect.

138. Among the amusements of schoolboys there are few more susceptible of application to useful or curious purposes than that of flying paper-kites. By means of such a machine, which he constructed by stretching a silk handkerchief over a wooden frame, Dr. Franklin demonstrated the identity of lightning with the electric fluid;* the paper-kite has been employed to convey a line to the shore from a vessel wrecked on a rocky coast;† and a few years ago, a Mr. Pocock, of London, made repeated experiments, by means of which he ascertained the possibility of travelling in a carriage drawn by two paper-kites, supported at a moderate elevation, and impelled by the wind. The elevation of the paper-kite in the usual manner, with a line attached to a loop on the under-side of the machine, is satisfactorily elucidated by Dr. Paris, who has shown that the ascent of the kite affords an example of the composition of forces, the mode of action of which is exhibited in the following diagram.



139. The kite is here represented rising from the ground, the line W denoting the direction and force of the wind, which falling on an oblique surface, will be resolved into two forces, namely,

To what useful purposes has the kite been occasionally converted? On what principle is its ascent to be explained?

* See Treatise on *Electricity*.

† See Transactions of the London Society for the Encouragement of Arts, Manufactures, and Commerce, vol. xii.

one parallel with it, and another perpendicular to that surface, and the latter only, represented by the line Y, will produce an effect, impelling the kite in the direction O A; and the tension of the string, at the same time, in the direction P T S, will cause the machine to ascend in the diagonal O B of the parallelogram O A B T.* The ascent of the paper-kite not only depends, as may be thus perceived, on the same principles as those which govern the movement of bodies on inclined planes; but it may also be fairly affirmed that the path of the kite in rising is an actual inclined plane, up which it is drawn, by the tension and weight of the string.

140. A well constructed kite may be made to ascend when there is little or no wind stirring; for, by running with it held by the string and inclined obliquely, the air on its inferior surface will be compressed, just as it would be by running with an expanded umbrella held out; and by veering out the string and running at the same time, the kite is drawn up an inclined plane which it forms for itself by the gradual compression of the successive portions of air over which it moves.

The Diving-bell.

141. As air produces peculiar effects when its density is inferior to that of the lower atmosphere, so likewise are certain effects produced by air, the density of which has been augmented by compression or otherwise. Condensed air, if not contaminated with deleterious gases, may be breathed with impunity by animals for a considerable time; though its effects are various on different individuals, and some experience considerable temporary inconvenience from inspiring it. Mr. Bille, of New York, has founded on this property of compressed air an improved method of bottling sparkling liquids, such as ale, cider, and perry. His plan consists in conducting the whole operation of drawing off, bottling, corking, and securing the liquors in question, within an air-tight chamber, into which such a quantity of air may be compressed by a condensing pump or engine, that it may always afford a degree of pressure on the surfaces of the liquors sufficient to prevent the escape of the gas to which they owe their sparkling quality.

142. But the most interesting and important purpose to which the respirability of compressed air has been applied, is that of enabling persons to descend to a certain depth beneath the surface of the sea, by means of the machine called a diving-bell. The

What path does it actually describe in rising?
How may the kite be made to rise in a calm?
How is the ascent in this case produced?
What effect on the respiration of animals is produced by air above the common density?
What application of such air has been made to purposes in the arts?

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* Philosophy in Sport made Science in Earnest. New edit. 1833, p. 236.

compressibility and impenetrability of atmospheric air may be both at once demonstrated by the simple experiment of holding by the foot an inverted beer-glass, and plunging it perpendicularly in a jar or basin of water, when the portion of air within the beer-glass will be compressed and diminished in bulk, in proportion to the depth to which the glass was pressed beneath the surface of the water: but a limit would occur beyond which manual force would not drive it. If a small bit of lighted wax-taper, attached to a cork, were placed on the water and included under the inverted glass, it would burn in the compressed air longer than in an equal bulk of air at its usual density; but the air would be consumed by the combustion of the taper till it became reduced to about one-third, and the residue would be found unfit for respiration and the support of animal life.

143. A diving-bell is merely a large conical or pyramidal vessel, made of cast iron, or of wood, the latter loaded with weights to make it sink. It is usually furnished with shelves and seats on the sides for the convenience of those who descend in it; and several strong glass lenses are fitted into the upper part for the admission of light. There is likewise a stop-cock, by opening which the air, rendered impure by respiration, may from time to time be discharged and rise in bubbles to the surface of the water; and provision must be made for the regular supply of fresh air, which may be sent down through pipes from one or more large condensing syringes, worked on the deck of a vessel above. The bell must be properly suspended from a crane, or cross-beam, furnished with tackles of pulleys, that it may be lowered, raised, or otherwise moved, according to circumstances.

144. Some have supposed that the ancients were acquainted with the use of the diving-bell, and apparent allusions to it occur in the works of Aristotle. But the earliest direct notice of such a machine is probably to be found in a tract "De Motu Celerrimo," by John Taisnier, who held an office in the household of the emperor Charles V. He states that some experiments were made in the presence of that prince, at Toledo, in 1538, by two Greeks, who descended under water several times in a brazen caldron, without wetting their clothes, or extinguishing lights which they carried in their hands.* Since the middle of the seventeenth century, diving-bells have been often used for the purpose of recovering valuable property which had been shipwrecked.

145. In recent times, the expense attending the construction of a diving-bell, and the difficulty of managing so unwieldy a ma-

How are the compressibility and the impenetrability of air demonstrated?

How is the power of compressed air to support combustion proved?

What is the description of the diving-bell?

How are the operators in a diving-bell supplied with air during their continuance beneath the surface?

What historical account is given of the invention of the diving-bell?

* V. Scholti Technica Curiosa, lib. vi. cap. 9.

chine, have led to the invention of less operose and more convenient methods of making submarine investigations; but there is one instance of the successful employment of diving-bells for the recovery of treasure from the sea, which occurred in 1831, and that attracted attention on account of the skill and enterprise displayed in the conduct of the undertaking. In December, 1830, a British frigate having sailed from Rio Janeiro for England, with 810,000 dollars on board, struck on rocks, and was sunk at Cape Frio. Captain Thomas Dickensen, an officer on that station, obtained permission to attempt the recovery of the treasure; and not being able to procure a diving-bell at Rio, he adaptod to the purpose the ship's iron water-tanks, and constructed a huge crane 158 feet in length, and 50 feet above the level of the sea, from which to suspend the bells. Though the bells were repeatedly lost, the undertaking was prosecuted by Captain Dick enson and other officers, till ultimately 750,000 dollars were recovered, besides a quantity of marine stores and other articles.

146. Diving habits, or jackets, adapted for descending under water, have been variously contrived; and among such machines are the Scaphandre, invented by the Abbé de la Chapelle;* and Klingert's machine for walking under water;† but these, though ingenious, are probably inferior to the apparatus recently employed at Portsmouth, England, by Mr. Deane. The essential part of his machinery consists of a capacious metal helmet, covering the head and neck, resting on the shoulders, and attached to the body by straps. In the front are three oval windows of strong plate-glass; from the lower part of the helmet passes a bent tube for the discharge of air which has been breathed; and from the upper part proceeds another tube connected with a flexible pipe, through which fresh air is forced from above. Armed with this head-piece, and a waterproof dress, the adventurer descends from the side of a ship by a ladder to the bottom of the sea, which he can explore at his leisure, and walk to any distance within the length of his air-pipe. To counterbalance the upward pressure of the water at any considerable depth, it is requisite that leaden weights should be attached to the body, in addition to the weight of the helmet, and thick leaden soles for the shoes.‡

147. Some curious inventions, for the purpose of submarine na-

What objection exists to the general use of diving-bells for submarine explorations?

What instance can you cite of the successful employment of these machines for the recovery of lost treasure?

How is Deane's diving apparatus constructed?

What limits the extent to which the diver can extend his examinations when using this apparatus?

How is the body prevented from rising from deep water in the excursions taken with diving dresses?

* V. Sigaud de la Fond Elem. de Phys., vol. ii. p. 249.

† See Tilloch's Philosophical Magazine, vol. iii. p. 172.

‡ Nautical Magazine.

vigation, have been invented in the United States. Robert Fulton, the successful inventor of the steamboat, contrived a machine of this kind, called a Torpedo;* and David Bushnell invented a submarine vessel in which a man might pass a considerable distance under water; and by means of this, and its accompanying magazine of artillery, an attempt was made to blow up a British vessel in the harbour of New York, during the late war with England.† This project appears to have failed merely from the difficulty or rather impossibility of attaching the magazine to the bottom of the ship, which was attempted by means of a sharp iron screw, which passed out from the top of the diving-machine, and communicated with the inside by a water-joint, being provided with a crank at its lower end, by which the engineer was to drive it into the ship's bottom. The machine affording no fixed point to act from, the power applied to the screw could make no impression on the ship; and thus this bold adventure was disconcerted.‡

Describe the method of Bushnell for blowing up an enemy's ships.
Why did this plan prove unsuccessful?

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* V. Montucla Hist. des Mathemat., t. iii. p. 78.

† For a description of this curious engine, see a paper on "Submarine Navigation," by Charles Griswold, in Silliman's American Journal of Science, vol. ii. p. 94.

‡ For a report on Norcross's diving apparatus, see Journal of the Franklin Institute for January, 1835, vol. xv. p. 25.

The following scientific treatises may be advantageously consulted in reference to the department of Pneumatics:—

Playfair's Outlines of Natural Philosophy, vol. i. pp. 242—262.
Library of Useful Knowledge, treatise on Pneumatics.
Gregory's Mathematics for Practical Men, pp. 346—352.
Ferguson's Lectures on Select Subjects, pp. 195—227.
Cambridge Mechanics, p. 377, where the motion of gases is treated to some extent, and p. 403, theory of the air pump and other machines depending on the atmosphere.
De Luc Recherches sur les Modifications de l'Atmosphere.
Philosophical Transactions, vol. lxvii. pp. 513. 653.
Cavallo's Philosophy, vol. ii.
Playfair on the Causes which affect Barometric Measurements, in the Edinburgh Philosophical Transactions, vol. i. p. 87.

ACOUSTICS.

1. THE science which has been designated by the terms Acoustics* and Phonics,† treats of the causes and effects of Sound, and the manner in which it is perceived by the organ of hearing. The idea of sound is excited in the mind when the motions which take place in any of the bodies around us are such as can be communicated to the auditory nerve and thence to the brain. This effect is produced by means of the organization of the ear, the tremulous motions or vibrations of the air being propagated to the tympanum or drum, a thin membrane which closes the aperture of the ear; behind the drum is a cavity in the bone which forms the side of the head, separated by another membrane from an inner cavity, from which branch off variously-formed tubes or canals, which, as well as the inner cavity called the labyrinth, are filled with a limpid fluid; and an expansion to the auditory nerve, or delicate layer of nervous fibres being distributed over the internal surface of the labyrinth and canals, it thus becomes the medium of sensation with regard to sound.

2. There is a passage called the Eustachian tube, which extends from the back part of the mouth to the cavity immediately behind the membranous drum, through which air passes, and therefore the drum vibrates freely when acted on by the sonorous undulations of the external air, which are communicated from the membrane of the drum by a chain of very minute bones and muscles passing from it to the membrane over the entrance to the labyrinth, and corresponding undulations being produced in the contained fluid, impressions are propagated to the nervous lining of the labyrinth, and thence to the brain.

3. Hence it must be apparent, that the sense of hearing, depending as it does on the perfect operation of so complicated an organ as the ear, may be impaired by various causes, or entirely destroyed when the essential parts of the organ are originally wanting, or so greatly injured by disease as to be incapable of performing their functions. Thus some persons are born deaf, the organization of their ears being so defective that they are ut-

What is the object of the science of acoustics?
Under what circumstances is the idea of sound excited in the mind?
How is the effect produced?
What is the tympanum of the ear?
What is the inner cavity of the ear designated?
How is its internal surface lined?
What appears to be the immediate instrument of sensation in regard to sound?
What is the position of the Eustachian tube?
What is the natural consequence, in regard to language, of an original want or an early destruction of the organs of hearing?

* From the Greek Ακουω, to hear.
† From Φωνη, a voice, or sound.

terly incapable of perceiving sounds, and therefore can never acquire the faculty of speech by imitating vocal language. Such unfortunate individuals, incapable of obtaining knowledge by the usual channels, may, however, be qualified for high degrees of mental cultivation by the modes of instruction contrived, or rather greatly improved, by L'Epée, Sicard, Braidwood, and others, who have most meritoriously devoted their talents to the instruction of the deaf and dumb.

4. Though the functions of the organ of hearing are clearly ascertained, as to the general principle of action, yet the peculiar purposes of the several parts are by no means equally obvious; nor is it certain that any of them, except the auditory nerve, are absolutely essential to the perception of sound. Some persons naturally have an aperture in the membranous drum of the ear, and in others a similar defect is produced by disease; but in either case, though the faculty of hearing is commonly somewhat impaired, it is not destroyed, not even when, owing to abscess in the ear, the chain of bones* between the membrane of the drum and that covering the entrance to the labyrinth has been disunited. In that case, probably, the vibrations of the air impinging on the inner membrane cause the requisite undulations in the fluid within the labyrinth.

5. There are persons who occasionally amuse themselves and their companions by drawing a quantity of tobacco-smoke into the mouth, and then expelling it through one or both ears; a feat which can be performed only by those who have a natural or artificial perforation of the membranous drum of the ear; and thus they can force the smoke through the Eustachian tube, into the cavity of the drum, and discharge it through the perforation just mentioned.

6. In practising the art of diving, it appears that those engaged in it on first going into deep water become subject to most intense pains in the ears, which continue till they have reached certain depths, when the sensation of something bursting within the ear with a loud report terminates the pain, and they can then descend as low as may be necessary without any further inconvenience. There can be no doubt that all this is occasioned by the vast pressure of the water on the drum of the ear, and its consequent rupture; and probably it would be found on investigation, that pearl-divers, and others accustomed to deep diving, have the auditory faculty more or less impaired.

What effect on the faculty of hearing has a rupture of the tympanum?

What experiment proves the existence of a passage between the mouth and the external ear?

What sensation precedes the relief obtained by divers when they first go into deep water?

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* This chain consists of three distinct bones, called, from their respective forms, the *hammer*, the *anvil*, and the *stirrup bones*,—*malleus*, *incus*, and *stapes*.

7. Though air is the usual medium of sound, it is not essential to the formation or the propagation of sonorous vibrations. Some substance however, either solid, liquid, or aërial, must form a continuous connexion between the sounding body and the ear; for sound cannot be conveyed through a vacuum. If a small bell be suspended under the receiver of an air-pump, in such a manner that it can be struck with a hammer without admitting air to it, when partial exhaustion has taken place, the sound will be weakened, and after the rarefaction has been carried as far as possible, no sound will be heard on striking the bell. If the experiment be made by inclosing the bell in a small receiver full of air, and placing that under another receiver from which the air can be withdrawn, though the bell when struck must then produce sound as usual, yet it will be quite inaudible, if the outer receiver be well exhausted, and care be taken to prevent the sonorous vibrations from being propagated through any solid part of the apparatus.

8. As sounds become weak when the air surrounding the sonorous body is rarefied, so on the contrary, any sound, as that of a bell, will be perceived to be much louder when the bell is struck in a vessel filled with highly compressed air, than when struck with the same force in a vessel of air of the common density. Hence, too, it happens that when a pistol is fired on the top of a high mountain, where the air is comparatively rare, the report is not so loud as when it is fired at the base.

9. That liquids conduct sound with no less facility than air may be ascertained by ringing a bell under water, when it will be heard as distinctly as when rung above the water. And a person diving under water would plainly hear the sound of a bell struck in the air at a moderate distance. If both the hearer and the sounding body be immersed in the same mass of water, the sound will appear much louder than when passing through an equal extent of air.

10. The propagation of sonorous vibrations through liquids may be rendered visible; for, on rubbing gently with a wet finger the edge of a drinking-glass, half filled with water, sound will be produced, and the surface of the water will be covered with minute undulations. The intensity or loudness of sound in fluids appears

What functioo does the air perform in regard to the sonorous body and to the ear?

What experiment proves the necessity of a medium for the transmission of sound?

What is the effect of highly condensed air on the loudness of sounds produced within it?

What other evidence is afforded of the effect of pressure on the intensity of sound?

How can we prove that liquids conduct sound?

Does it appear from experiment that liquids are better or worse conductors of sound than air?

How is the propagation of sonorous vibrations in liquids rendered visible?

to be augmented in proportion to the increase of their specific gravity. Thus water, being so much denser a fluid than air, sounds produce a stronger effect in the former medium than in the latter; and therefore it may be regarded as a wise provision of the Author of Nature, that the organs of hearing in fish are much less perfectly developed, and consequently less sensible to the impressions of sound than those of terrestrial animals.

11. Solids, when they possess elasticity, convey sounds to the ear more readily and effectively than gases or liquids. If a person, hard of hearing, places one end of an iron rod between his teeth, while the other end rests on the edge of an open kettle, he will understand what is said by another directing his voice into the kettle, more distinctly than if the voice of the speaker passed through the air, so that he might converse in this manner with any one at a distance at which he would not hear under common circumstances. When a stick is held between the teeth at one extremity, and the other is placed in contact with a table, the scratch of a pin on the table may be heard though both ears be stopped. When sounds are propagated in this manner, the sonorous vibrations must be conveyed through the mouth and along the Eustachian tube to the interior part of the organ of hearing.

12. Among the evidences of the transmission of sound through solid bodies, may be mentioned the common experiment of tying a ribbon or a strip of linen, cotton, or flannel, to the upper part of a large poker, so that it may be supported vertically by holding the two ends of the ribbon; which are to be brought in contact with the ears, and pressed against them, so as to close them, then on swinging the poker so that it may strike as gently as possible against a bar of the fire-grate, or any other metallic substance, a deep sound will be distinctly heard like the tolling of a large bell; and yet if the ribbon be removed from the ears, and the poker suspended by it, and struck in the same manner, the sound will be hardly perceptible. Some experiments will subsequently be noticed, which show that sound not only passes much more readily through elastic solids than through air, but also that it traverses the former with abundantly greater velocity.

13. That peculiar kind of motion in bodies which gives rise to the sensation of sound has been characterized by the term vibration, because a striking analogy may be traced between the tremulous agitation which takes place among the particles of a sounding body, and the oscillations of a pendulum. The nature of sonorous vibrations may be illustrated by attending to the visible

According to what circumstance does their conducting power appear to be augmented?

What conducting power for sound is possessed by elastic solids compared with that of other classes of bodies?

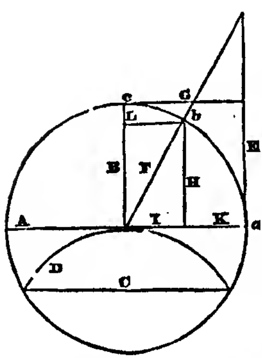
In what manner may a person partially deaf be enabled to carry on a conversation?

What easy experiment illustrates the transmission of sounds by solids?

What name is given to the motion by which sound is produced?

INTRODUCTION.

1. Among the several distinctions which have been made in human knowledge, those of most importance to be noticed in the commencement of the present work, regard the discrimination between the mathematical and the physical sciences. The latter are so far dependent on the former, that some knowledge of mathematics is absolutely necessary, previously to entering to any extent on the study of physical or natural philosophy. A general acquaintance with at least the elementary branches of mathematics, as arithmetic, geometry, and trigonometry, may be expected to have been acquired by all tolerably well educated persons, as usually forming a part of a common school education. Physical science, or natural philosophy, constitutes the exclusive object of the present volume, in order to the perusal of which, with profit and advantage, it will be requisite that the reader should not be ignorant of the names and general properties of geometrical lines and figures. The following diagram and explanatory observations are therefore introduced, as they may be useful to those who are but slightly acqnainted with mathematics, and may sometimes save the better informed student the trouble of referring to other books for information, respecting the signification of particular terms.



A a Circle.
A *a* its Diameter.
B the Radius.
C a Chord.
D an Arc.
E a Tangent.
F a Secant.
G a Co-tangent.*
H the Sine of Arc *a b*.
I the Co-sine.
K the Versed Sine.
L the Sine of complemental Arc *b c*.

2. Every circle is supposed to be divided into 360 degrees, and the line which bounds the circle, and on which therefore these degrees may be marked, is called its circumference. Any lines equidistant from each other throughout their whole extent

Describe the several parts of the diagram represented in the margin.
Into how many degrees is a circle supposed to be divided?
What are parallel lines?

are termed parallel lines. Two lines not parallel but in the same plane must, if sufficiently produced, meet in a point, which is called an angle. Angles are principally distinguished by the relative inclinations of the lines by which they are formed. When one line meets or crosses another perpendicularly, the angles they form are called right angles; and any angle smaller than a right angle, is styled an acute angle, and any greater an obtuse angle. But angles are more precisely measured by reference to the number of degrees contained in an arc of a circle joining the two lines by which an angle is formed. Thus a right angle must be included within an arc of a circle equal to a quadrant, or the fourth part of 360 degrees, namely, 90 degrees; and an acute angle included within an arc only half the extent of a quadrant will, of course, be an angle of 45 degrees.

3. A space or flat surface, inclosed by three lines, is the most simple of all definite figures, and is called a triangle. Among the varieties of these figures are the rectangular triangle, so named because it has one right angle; the equilateral triangle, which has three sides of equal extent; the isosceles triangle, which has only two equal sides; and the scalene triangle, all the sides of which are of different lengths. Any space inclosed by four lines is called a quadrilateral, or four-sided figure. Among such are included the square, having four equal sides and right angles; the rectangle, or oblong square, having only the opposite sides equal; the lozenge, which has equal sides and unequal angles; and the trapezium, which has only two of its sides parallel. When the sides of a quadrilateral figure are parallel, it is termed a parallelogram. A line joining two opposite or alternate angles, is called a diagonal. Any figure having several angles, and consequently several sides, is named a polygon.

4. Solid figures include the tetraedron, or four-sided solid, which is the most simple figure of the kind, as no solid can have less than four sides; and when the number of sides is greater, the figure is called either a hexaedron, an octaedron, an icosaedron, or a polyedron, according to the number of its sides.

5. Among polyedrons may be distinguished the prism, formed

What constitutes an angle?
By what names are different angles distinguished?
How are they accurately measured?
How many degrees of a circle are contained in a right angle?
What is the most simple definite figure?
What is a rectangular triangle? an equilateral triangle? an isosceles triangle? a scalene triangle?
What is a four-sided figure called?
Describe some of the figures that come under this denomination.
What is a diagonal?
What is a polygon?
What is the most simple of solid figures?
How many sides has a hexagon?
How many an octagon? an icosaedron and a polyedron?
Of what form is a prism?

of parallelograms only, or of parallelograms and two polygons of any number of sides. Among the prisms may be specified the parallelopiped, formed of six parallelograms only; and among the parallelopipeds may be noticed the cube, having six square sides. The pyramid is a polyedron, formed by a polygon of any kind as its base, and as many triangular planes as the polygon has sides: the point where all the triangular planes unite is called the summit of the pyramid. The most simple solid of this kind is the tetraedron, or four-sided pyramid, including the base.

6. The terms sphere, cylinder, and cone, designate solid figures, having either entirely or partially curved surfaces; and the expressions spheriod, cylindroid, and conoid, are used to denote solid figures, more or less resembling a sphere, a cylinder, or a cone, respectively.

Natural Philosophy is the science which explains the causes of the various properties of bodies in general, as shown by the changes which they undergo in any particular circumstances, or the changes which they may occasion in other bodies, under certain circumstances. The province of natural philosophy does not extend to the explanation of the doctrine of final causes, or the immediate and positive reasons why particular effects take place, or why certain bodies possess the peculiar properties with which they are endowed; but it enables us to appreciate the consequences of any body being placed in a given situation, or to foretel what will be result of any body acting on another in a certain manner.

7. Thus, we know nothing of the absolute cause of gravity or weight, which is that property of bodies in consequence of which they fall towards the surface of the earth, if raised in the air by any force and then dropped; but natural philosophy, while it leaves us in ignorance of the final cause of gravity, enables us to determine a vast variety of curious circumstances with respect to falling bodies. Thus, it is found that a heavy body, as for instance a marble or a musket-ball, dropped from a high tower, would fall faster as it approached near to the ground than it would in passing through the former part of its descent; and the rate at which a body falls through a given space has been ascer-

How is the parallelopiped formed?
How many sides has a cube?
How is a pyramid formed?
Where is the *summit* of a pyramid?
What is the most simple solid of this kind?
What kind of figures are designated by the terms sphere, cylinder, and cone?
How are those figures denominated that more or less resemble these figures?
What is Natural Philosophy?
What are some of the doctrines beyond the explanation of Natural Philosophy.
What is there in the subject of *gravity* which is inexplicable by natural philosophy, and what does this science enable us to determine respecting it?

tained by experiment, and can be calculated with the utmost exactness. So as to the final cause of electric and magnetic attraction various opinions have been advanced, and it is still involved in obscurity; but we know by experience that a magnet attracts iron with considerable force, and that a thin bar of magnetic iron, accurately poised on its centre, will, when left free, point towards the north with one end, and towards the south with the other; and on the latter property depends tho action of the mariner's compass, by means of which the sailor, crossing the pathless sea, is able to ascertain in what direction his vessel is steering; and to this little instrument, which was unknown to the ancients, we are in a great degree indebted for the important discoveries of modern navigators.

8. Whether light and heat are owing to matter or motion has been left among the questions which philosophy has hitherto been unable satisfactorily to decide; but the effect of light on bodies, whether opaque, transparent, or semi-transparent, the velocity with which it passes through space, and the manner in which it is modified by optical glasses of various forms, are among the numerous interesting and surprising properties of light, which natural philosophy has laid open to our investigation, and which we are enabled to verify and illustrate by means of mathematical calculation; and the phenomena of heat and cold, with which we are so intimately familiar, from the sensations they occasion, are equally hidden as to their final cause, and equally wonderful and curious as to their effects, the latter of which alone afford an ample field for the experiments and deductions of the philosophical inquirer.

9. Astronomy presents a boundless field for research, and notwithstanding it has been explored with signal success in modern times, yet the most important discoveries that have been made only serve most distinctly to evince that the wisest and most successful investigators of the phenomena of the science have merely entered on the confines of knowledge, and enabled us to form some imperfect estimate of those boundless regions which display an inexhaustible field for future speculation and inquiry. It has indeed been ascertained that the sun and the planetary and other bodies which constitute the solar system, are influenced by the same moving power as that which causes the fall of an acorn to the ground, when detached from the oak on which it was pro-

What has experience taught respecting magnetic and electric attraction?

What questinn respecting the nature of light and heat has been hithertn undecided by philosophy?

What are some of the properties of light which natural philosophy has laid open to our investigation, and how are these to be verified?

In regard to heat, what points are known and what unknown?

What conclusions have been drawn from the most successful investigations in astronomical science?

What has been ascertained to be the moving power that influences the bodies of the solar system?

duced; and that the attractive force which retains the moon in her orbit, and causes her reaction on the fluid parts of the terrestrial globe wo inhabit, producing the tides, may be estimated with accuracy, and subjected to mathematical calculation. But there are numberless topics of inquiry—with regard to the constitution of the sun, the nature of comets, and the causes of their peculiar motions, the kind of medium which occupies the space beyond the atmospheres of the earth and planets, and the relations that may exist between our solar system and the numberless other systems, the existence of which may be inferred from the appearance of the starry heavens—which may for an indefinite period serve to exercise the talents of men of genius and learning, but concerning which we can hardly hope to attain any knowledge approaching to certainty, till discoveries and inventions in other sciences provide us with means for investigating the works of nature, as much superior to those which we at present possess, as our instruments of research surpass those employed by the ancients.

10. "The proper business of philosophical inquiry," says Leslie, "is to study carefully the appearances that successively emerge, and trace their mutual relations. All our knowledge of external objects being derived through the medium of the senses, there are only two ways of investigating physical facts—by *observation* or *experiment*. Observation is confined to the close investigation and attentive examination of the phenomena which arise in the course of nature; but experiment consists in a sort of artificial selection and combination of circumstances, for the purpose of searching minutely after the different results.

11. "The range of observation is limited by the position of the spectator, who can seldom expect to follow nature through her winding and intricate paths. Those observations are of the most value which include the relations of time and space, and derive greater nicety from their comprising a multiplied recurrence of the same events. Hence Astronomy has attained a much higher degree of perfection than the other physical sciences.

12. "Experiment is a more efficient mean than observation for exploring the secrets of nature. It requires no constant fatigue of watching, but comes in a great measure under the control of the inquirer, who may often at will either hasten or delay the expected event. Though the peculiar boast of modern times, yet the method

What is the effect of this force upon the moon, and indirectly upon the earth? How are these effects to be estimated?

What subjects of inquiry in astronomical science, are supposed to lie beyond our present means of investigation?

What does Leslie affirm to be the proper business of philosophical inquiry?

What are the only two methods of investigating physical facts, and what is the province of each?

What circumstance limits the range of observation?

What observations are of most value?

Which is the more efficient means of exploring the secrets of nature?

of proceeding by experiment was not wholly unknown to the ancients, who seem to havo concealed their notions of it under the veil of allegory. *Proteus* signified the mutable and changing forms of material objects; and the inquisitive philosopher was counselled by the poets to watch that slippery dæmon when slumbering on the shore, to bind him, and compel the reluctant captive to reveal his secrets.* This gives a lively picture of the cautious and intrepid advances of the skilful experimenter. He tries to confine the working of nature—he endeavours to distinguish the several principles of action—he seeks to concentrate the predominant agent—and labours to exclude as much as possible every disturbing influence. By all these united precautions, a conclusion is obtained nearly unmixed, and not confused, as in the ordinary train of circumstances, by a variety of intermingled effects. The operation of each distinct cause is hence severally developed."†

13. The object of Natural Philosophy may be stated to be the study of the general properties of unorganized bodies, or inert substances in the state of *solids*, *liquids*, *airs*, or *gases*, and those which have been termed *incoercible* or *ethereal fluids*. It is also within the province of the physical sciences to examine the mechanical action which bodies, in their different states, may exercise on each other, and the different circumstances connected with their movements.

14. The various effects of the motions and operations of bodies depending on their general properties have hence been made the foundation of several distinct sciences or branches of knowledge, which have been usually classed with reference to the several forms of matter called solids, liquids, and airs, or to certain kinds of phenomena, supposed to depend respectively on the presence and action of some imponderable modification of matter or ethereal fluid, to which have been referred thermometrical, optical, electrical, and magnetic phenomena. Hence a treatise on Natural Philosophy may be conveniently arranged under the different departments of (1.) MECHANICS, or the doctrine of equilibrium and motion as respects solids, including Statics and Phoronomics or Dynamics; (2.) HYDROSTATICS, including Hydrodynamics or Hydraulics, relating to the equilibrium and motion of liquids; (3.) PNEUMATICS, including Aerostatics, and Aerodynamics, or the effect of forces on air and other gaseous fluids; (4.) ACOUSTICS, or the theory of sound, comprehending observations on musical and vocal sounds; (5.) PYRONOMICS, or the investigation of the causes and effects of heat, or more generally of change of temperature;

What is the object of Natural Philosophy?
How have its divisions been formed?
What are the different departments under which a treatise on Natural Philosophy may be properly arranged?
Of what does each of these departments treat?

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* V. Virgil. Georgic. lib. iv.
† Introduction to Elements of Natural Philosophy.

(6.) Photonomics or Optics, including the theory of light and vision; (7.) Electro-magnetism, which treats of the causes of electric and magnetic attraction and repulsion.

15. The idea of *absolute* or *indefinite space* is obtained by abstraction, or conceiving in imagination the absence of all bodies, or of all the properties of matter. Every part of this space, or rather of this imaginary void or vacuum, which can be conceived to be included in any way between limits, is called *relative space.* The term *body* is used to designate limited extension, to which are attached any of the properties of matter. That which distinguishes in general a simply extended body from a void space or vacuum, is the property of impenetrability, that is, the quality in consequence of which a body occupies a certain space, and excludes from it all other bodies.

16. We acquire a knowledge of the properties of matter through our senses, either by immediate observation, or by experimental inquiry with the aid of instruments. The senses of sight and feeling afford us abundance of information concerning the properties of bodies around us, but our knowledge may be vastly extended when we assist the former by means of optical glasses, which open new worlds to our view, or when by means of delicate instruments we measure degrees of temperature, electricity, or magnetic power.

17. Solid bodies are those which, like stone or wood, present a sensible resistance when touched, pressed, or handled. They may be cut into various forms, and preserve without difficulty the figures which are given to them, or which they possess naturally. Sand, powders, and similar substances consist of small particles not united together; yet though, collectively, masses of sand present but little resistance to pressure, the individual minute particles have all the characteristics of solid matter, and though readily dispersed by force, they may be assembled in heaps more or less considerable.

18. Liquid substances are those which, like water, manifest immediately to the touch but a very feeble resistance, but quite sufficient to indicate their presence, even when in a state of repose. They cannot be grasped between the fingers like solid bodies, nor can they be collected in heaps, or made to take any particular figure, except that of the vessel in which they may be included.

19. Aeriform fluids are in general invisible bodies, which like the air surrounding us cannot be felt, and afford no evidence of their presence to the sense of touch when in repose. But their existence is ascertained with abundant certainty when they are in motion; thus no one can doubt the materiality of atmospheric air after

How do you obtain an idea of *absolute* or *infinite* space?
What is relative space?
What is meant by the term *body?*
What is the property of impenetrability?
By what means do we acquire a knowledge of the properties of matter?
What are *solid* bodies? liquid substances? aeriform fluids?

experiencing the violent exertion necessary in walking against a high wind. Aeriform bodies may be confined in vessels, whence they exclude liquids or other bodies, demonstrating their impenetrability, though they readily become compressible to a great extent, but there are limits beyond which it is impossible to reduce them.

20. Incoercible or imponderable fluids do not manifest their existence by the exhibition of impenetrability or weight, which have usually been regarded as essential properties of matter; and they must, therefore, be considered as hypothetically admitted, in order to account for certain phenomena, which appear to depend on the presence and action of one or more ethereal media.—That light is such an imponderable fluid, emanating from the sun, was one of the generally received doctrines of the Newtonian Philosophy; the caloric or matter of heat of the French chemists was supposed to be a fluid of a similar nature; and men of science who have written concerning magnetism and electricity have vaguely employed the terms magnetic fluid and electric fluid to designate the unknown causes of the phenomena they describe.

21. At present it is perhaps the more prevalent opinion of philosophic inquirers that there exists at least one kind of ethereal, imponderable medium, the different modifications and modes of action of which give rise to the various phenomena of light, heat, and electro-magnetic attraction and repulsion. Thus it may be supposed that as sound is conveyed to our ears by the vibrations of the air, so light affects our eyes through the immensely more rapid vibrations of the electro-luminous ether. The existence of such a medium, manifesting neither weight nor impenetrability capable of being appreciated by the most delicate instruments, may be fairly inferred from the movements which take place in bodies under certain circumstances when all the ponderable and coercible kinds of matter have been carefully excluded, and these movements therefore must be ascribed to the presence of an ethereal influence, which can penetrate glass and other dense substances which are impervious to the rarest gases or most attenuated and subtile vapours with the existence of which we are acquainted.

22. But such speculations, if not rather curious than useful, would, if extended, be incompatible with the plan and objects of the present work. Therefore, though it would have been improper to have omitted all mention of them, they must be dismissed for the present, with the preceding short notice; especially as opportunities for resuming them will occur in some of the ensuing treatises.

How is their existence ascertained, and how is their impenetrability demonstrated?

How do the *incoercible* or *imponderable* fluids differ from these?

What have hitherto been considered imponderable fluids?

What is the present more prevalent opinion respecting the imponderable medium?

MECHANICS

1. There is perhaps no department of Natural Philosophy of such extensive importance as Mechanics, since its principles are founded on those properties of matter which are among the most obvious and essential,—namely, Mobility and Weight; and the effects produced by the operation of these properties are so distinct and certain, that they can be subjected to mathematical calculation. Hence Dr. Wallis has described Mechanics, with some degree of propriety, as the "Geometry of Motion."

2. The designation of this branch of knowledge, like most other scientific terms, is derived from a Greek word,* signifying a *Machine;* and Mechanics may be considered as the Philosophy of Machinery, or the Theory of Moving Powers. Many writers have treated of this science under two heads, regarding those principles which relate to the gravity or weight and to the equilibrium of bodies, or the powers which preserve bodies in the state of rest, as the subject of the doctrine of Statics;† and the principles relating to the causes of movement, or the forces producing motion, acting by means of solids, as forming the subject of the doctrine of Dynamics.‡ But, as the respective states of bodies at rest, and bodies in motion, may be most correctly considered as the consequences of different modes of action of the same causes, they may be instructively illustrated by showing their relations to each other, for which reason it will be proper to treat of them in conjunction, rather than separately.

3. From this statement of the nature and objects of Mechanics, it will at once appear that we have by no means overrated the importance of an acquaintance with this science to the Student of Natural Philosophy. For all motions are more or less subject to the laws of Mechanics, and without a knowledge of these laws, it is impossible to appreciate the effects, or calculate the consequences, of those motions of the celestial bodies which occasion the phenomena of Astronomy; or of those properties of fluids, whether liquid or gaseous, on which depend the principles of Pneumatics, Hydrostatics, and Hydraulics; or indeed of any circumstances affecting the ponderable forms of matter. And those sciences which relate to Heat, Light, Electro-magnetism,

Upon what properties of matter are the principles of mechanics founded?

What definition is given of mechanics?

Under what heads has this science generally been treated?

How extensive is the application of mechanical principles to other departments of science?

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* Μηχανη.

† From the Greek verb Στάω, to stand, or be fixed; or from Στασις, the act of standing.

‡ From the Greek word Δυναμις, power or force.

Vital Power, either in Animals or Vegetables, or any other phenomena which appear to be independent of the force of gravitation, yet derive most important aid from Mechanics; for it is chiefly by means of mechanical instruments that the influence of heat, light, electricity, magnetism, or the effects of vitality, as in the motion of the blood in animals, or of the sap or other fluids in vegetables, can be estimated. Mechanics may, therefore, be considered as the basis or groundwork of the other Physical Sciences, or branches of Natural Philosophy.

4. Previously to entering on the consideration of the Theory of Mechanical Powers, it will be necessary to show the nature and effects of Mobility, or the capacity for motion, and of Weight, or the gravitation of bodies,—as these are the general properties of matter on which, as already stated, the phenomena of Mechanics depend.

Mobility.

5. Every individual body, or portion of matter, must take up a certain space. This may be considered as the absolute place of the body, in reference to its situation simply and singly; or as its relative place, or situation with respect to other bodies. The relative situation of a body may be changed either by its own motion, or by the motion of the bodies around it. A body may exhibit the appearance of actual motion, or absolute change of place, while it remains at rest, its change of place being only relative. Thus, the Moon, when a train of thin fleecy clouds is passing over its face, if we attentively fix our eyes on it, seems to move, and the clouds to stand still, though this is only an apparent motion of the Moon, in a direction contrary to that in which the clouds are really moving. And if we hold a common eyeglass, of any transparent substance, a few inches before the eyes, and move it backwards and forwards, looking through it at any object, as an inkstand or knife, which remains unmoved, it will, as in the former case, exhibit an apparent motion, arising from the actual movement of the glass.

6. Mobility is the capacity of a body for change of place by its own motion, it therefore infers the capability of real or actual motion, and not of relative motion only. Yet this change of place may sometimes be most readily estimated by the consequent relative motion which accompanies it. Thus, a person sailing in a boat on a smooth stream, or going swiftly in a coach along an even road, would hardly perceive the motion of the vehicle except by the change of scene, and trees or buildings on the banks of the stream, or by the road-side, would seem to move in an opposite direction from that of the real motion of the boat or carriage. Every tolerably well-informed person now admits

What is meant by the *absolute* place of a body?
What by the *relative?*
What is *mobility?*

that the earth moves, and the sun stands still; but the motion of the former is not perceptible, and the apparent daily motion of the latter, being so obvious to our senses, was, till within the last three centuries, considered as a real motion, the existence of which could not even be questioned with impunity.

7. Without some active cause motion can neither commence nor cease; since a body in the state of rest would always remain unmoved, if never subjected to the influence of a moving force, and on the contrary, a body when set in motion would go on to move for ever, if it met with no opposition to its progress. I may seem inconsistent with this doctrine, that any body set in motion, within the range of our observation, will continue to move without a fresh impulse for a time, but at length will slacken its speed, and finally resume the state of rest. Thus, a cannon-ball will pass a certain distance when discharged from the mouth of a cannon, but if it does not strike a solid body, still it will ultimately fall to the ground; and a marble or a cricket-ball thrown forwards with the hand, if it meet no obstacle, will reach only a certain distance, proportioned to the force used in throwing it.

8. In both these and all similar cases, the termination of the motion of the moving body is owing chiefly to two causes. The first of these is gravitation towards the earth's centre, common to all bodies, and which constantly tends to keep them at rest, pressing on the surface of the earth with a degree of force proportioned to their weight and bulk; or, if, as in the case of the cannon-ball, they pass through the air, the force of gravitation then tends to draw them continually nearer to the earth, till at length they fall and rest upon it. But the second and more obvious cause of the decay of motion is the resistance of the medium through which the moving body takes its course; and thus, a body moving through the air, like the cannon-ball, gradually becomes less and less able to pass forward till its moving force is destroyed. It will be readily perceived, that the resistance of the medium to the body which passes through it, must depend much on its density or consistence; thus, a ball driven by a certain force would pass further through the air than through water, and further through the latter than through a denser fluid, as brine or syrup, or through solids, as sand or clay.

9. Another circumstance which will affect the motion of a body, with relation to the medium through which it travels, must be taken into the account, and this is the form of the moving body. A small body will meet with less resistance than a large one of the same weight; and a body which presents an extensive

State some familiar examples, and show how real and apparent motion may best be distinguished.

How is a body at rest to be put in motion, and when in motion, how brought to rest?

What other circumstances go to retard or accelerate the motion of bodies?

surface to the medium through which it moves, will be retarded in its passage much more than one with a small surface. A sheet of paper stretched out to its full extent, and suffered to fall a few feet, and then folded up into a small compass, and again suffered to fall from the same height, will afford an exemplification of the resistance of the atmosphere to falling bodies; and an illustration of a different kind, but to the same purpose, may be drawn from the advantage which sharp-edged and pointed instruments have over blunt ones in penetrating hard or tough substances. A body moving in contact with a solid substance, as when it is rolled or dragged along the ground, is also affected by friction. This obstacle to motion is proportioned to the roughness or smoothness of the surface over which the body passes: thus, a marble thrown with any given force will run much further along an even pavement, than along an equally level gravel walk; and still further along smooth ice. Here again the form of the moving body has much influence on the velocity and extent of motion; for the fewer the points of contact between the surface and that which passes over it, the more freely will motion take place.*

10. All bodies subject to our control are exposed to the operation of gravity, in various degrees, and from this cause, independent of the resistance of the medium which they traverse, or of the effect of friction, their motions cannot be indefinitely continued, but must decline and terminate in a given time, according to the circumstances in which they are placed. But though perpetual motion cannot be exhibited by any methods which human skill or industry can contrive, yet we have continually before us the display of bodies which have been moving with undiminished velocity for ages past, and which no power but that which governs all nature can prevent from moving in the same manner for innumerable ages to come. The bodies to which we refer, as will probably be anticipated, are those whose motions are the objects of the science of Astronomy; and though that subject will not come under our immediate discussion, yet the general nature of the forces which occasion the revolution of the celestial bodies will be explained, and the causes of their uniform and uninterrupted motion will be illustrated.

11. That state of bodies just described, in which motion or the cessation of motion can take place only in consequence of an extraneous cause, has been termed Inertia, which signifies inac-

What are some of the examples which illustrate this point?
What other cause is there, independent of these, which operates upon all bodies, limiting their motion and precluding the possibility of perpetual motion by human skill?
What is *inertia?*

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* This statement is to be understood as limited by the greater or less difficulty with which the surface can be abraded.

tivity, equally opposed to motion when at rest, and to rest when in motion; so that if a given force is required to make a body move with a certain velocity, the same force will be required to destroy its motion. When a garden roller is being drawn along a level surface, the exertion necessary to stop it suddenly, at any given point, would be precisely the same as would be required to move it backward, if it were at rest, and of course the same that was applied to set it in motion at first.

12. Any force applied to produce motion may be called Power or impulse, which may be either continued, as in the case of pressure, or intermitting, as in the case of impact or percussion. Whatever opposes motion so as to retard the moving body, destroy its motion, or drive it in a contrary direction, may be termed Resistance, and its effect, reaction or counteraction. It is one of the laws of motion that action and reaction are always equal and contrary. Thus, in pressing down the empty scale of a balance, while the other scale held a five pound weight, it is obvious that the force exerted must be equal to five pounds; but if one scale had been loaded with fifteen pounds, and the other with only ten, the equilibrium might still be preserved by pressing on the latter with a force equal to five pounds only. And if a man, sitting in a boat on a canal, draws towards him, by means of a rope, another boat of equal weight, they will meet at a point half-way from the places whence they began to move. Suppose, however, the second boat to be so laden as to be twice the weight of the first, it must move the slower of the two, and consequently the point of meeting would be nearer the second boat than the first. If a body in motion strikes another body of equal mass at rest, the two bodies will move together, but with only half the original velocity of the first, the other half having been expended in overcoming the inertia of the second body. Corresponding effects will take place, whatever difference there may be between the masses of the two bodies; for if the second body should be double the mass of the first body, the common velocity after the impact of the two bodies would be one-third that of the first; and if the mass of the first body be to that of the second, as 5 to 7, the common mass after impact will be 12; and as the second will deduct from the motion of the first in proportion to its mass, the motion lost by the first body will be seven-twelfths, and the motion retained would be five-twelfths.

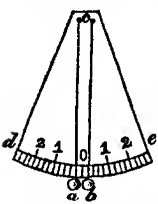
13. If two bodies are both in motion in the same direction, and one overtake and impinge on the other, suppose the masses of the two bodies to be the same, and the velocity of the first to be 7, and that of tho second to be 5, their common velocity after impact will be 6, or half the sum of the two velocities. But if the masses are unequal, the mass of each must be multiplied sepa-

What is *power?*
What resistance?
What is one of the laws of motion?
Give some of the illustrations.

rately by its velocity, and the products added together, and their sum divided by the sum of the two masses will give the common velocity. When two bodies are moving in opposite directions, with the same velocity, and having equal masses, action and reaction being equal, both motions will be destroyed. Suppose, however, the masses to be alike, and the velocity of the first body to be 10, and that of the other to be 6, the first body will lose 6 parts of its velocity, which will be requisite to neutralize or destroy the opposite velocity of the second body, and the remaining 4 parts of the velocity of the first body being divided between the two, they will move together in the direction taken by the first body with a common velocity equal to 2.

14. When the masses, as well as the velocities, are unequal, the common velocity of two bodies after impact may be found by multiplying the numbers denoting the masses by those expressing the velocities respectively, subtracting the less product from the greater, and dividing the remainder by the sum of the numbers denoting the masses: the quotient will then show the velocity with which the bodies will move together, in the direction of the body having the greatest quantity of motion.

15. An experimental illustration of the equality of action and reaction in the collision of bodies may be thus exhibited:



Suppose *a* and *b* to be two inelastic balls,* suspended together at *c*, by threads of equal lengths, so that they may be in contact when at rest; and let *d e* be a graduated arc, over which the balls may oscillate freely; then, if the ball *b* be moved a certain number of degrees towards *e*, and let fall so that it may impinge on the ball *a*, both together will move towards *d*, through a number of degrees proportioned to their common velocity.

Since it appears from the foregoing observations to be an established principle of Mechanics, that the force or impetus of a body in motion is to be estimated by its mass and velocity, it must be concluded that a body, the mass of which is very inconsiderable, may be made to act with the same force as another body the mass

How do you find the common velocity of two equal bodies which impinge against each other? state separately the cases where one of them is at rest before impact, when they move in the same and when in opposite directions.

How do you find the common velocity after impact when the masses as well as velocity differ?

Describe the experiments which demonstrate the equality of action and reaction.

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* No substance in nature is wholly destitute of elasticity, but soft clay, which is among the least elastic of solid bodies, may be used to make the balls for the above experiment.

of which is much greater, provided the smaller body has a velocity communicated to it greater than the velocity of the larger body, in the same proportion that the mass of the latter surpasses that of the former. Thus, a pincushion weighing half an ounce might produce as great an effect as a cannon-ball weighing thirty-six pounds, provided the pincushion had 1152 times the velocity of the cannon-ball; for 1152 half ounces being equal to 36 pounds, it must be obvious that the velocity of the pincushion would be just so much greater than the velocity of the cannon-ball, as the mass of the latter would be greater than that of the former.

16. Hence as the momentum or effect of moving force is to be estimated by the velocity of the motion and the weight or mass of the moving body taken together, it may be perceived how it happens that a small mass may produce an extraordinary effect when moving with great velocity. Thus, a tallow candle fired from a gun will pierce a deal board. On the other hand a great effect may be produced by a small velocity if the moving mass is extremely great. As for instance, a heavily laden ship of great burden, afloat near a pier wall, may approach it with a velocity so small as to be scarcely observable, yet its force will be sufficient to crush a small boat.

17. When two bodies meet in consequence of moving from opposite directions, each body will sustain a shock as great as if one body at rest had been struck by the other with a force equal to the sum of both their forces. Suppose two persons of equal weight walking in opposite directions, one at the rate of two miles an hour, and the other at the rate of four miles, if they should suddenly come in contact, each would receive a shock as great as if he had been standing still, and another had run against him moving at the rate of six miles an hour. In the ancient tournaments when mailed knights met in full career, prodigious must have been the shock when the collision was direct, and both would often be overthrown with a force proportioned to their joint weights and velocities. So when two vessels under sail run foul of each other, suppose one of them eight hundred tons burden, and the other twelve hundred tons, their velocities or rates of sailing being equal, each would sustain a shock equal to that which a vessel would receive if at anchor, and struck by another vessel of two thousand tons burden, sailing at the same rate with the vessels in question. Yet though the shock would be the same, the consequences would be most disastrous to the smaller vessel, the other being protected in a greater degree from injury by its superior strength and bulk.

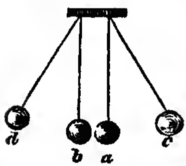
18. Elasticity being a common property of matter, and many substances employed for a variety of purposes, as several kinds of wood and metal, possessing that property in a high degree, its

What remarkable examples can be cited of the effect of momentum on bodies at rest?

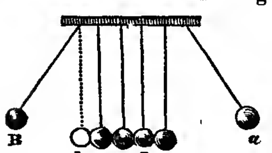
What practical illustrations can be given of the effect of bodies encountering each other when moving in opposite directions?

influence in modifying the operation of moving forces must not be neglected.

The different effects exhibited by bodies almost inelastic and those which are highly elastic may be illustrated by the simple experiment of dropping a ball of soft clay or wax from any given height on a solid pavement, and then letting fall from the same height a ball of box-wood or ivory of equal weight with the clay. The first ball will give way to the pressure of the pavement, and become dented or flattened on the side on which it rests, while the latter ball will rebound from the pavement with a force proportioned to the height from which it fell. This resiliency or rebound, in an ivory ball, is partly occasioned by its giving way to the pressure of the pavement, but unlike the clay it recovers its shape almost instantaneously, its surface thus acting as a spring against the pavement. That a hard substance like ivory is compressed by striking against a similar substance, may be shown by making a small dot with ink on the surface of one ball, and then bringing it gently in contact with another ball at that point, when a small mark will also appear on the latter ball; but if the balls, one being marked as before, be brought into contact with considerable force, as by pressure or collision, a much larger mark will be found on the latter ball than before; proving that, though both have recovered their shape, they must have undergone compression.



19. Let two ivory balls of equal weight, *a b*, be suspended by threads, as in the annexed figure, if the former be then drawn aside to *c*, and suffered to fall against the latter, it will drive it to *d*, or a distance equal to that through which the first ball fell; but it will itself rest at *a*, having given up all its own moving power to the second ball.



If six ivory balls of equal weight be hung by threads of the same length, and the ball *a* be drawn out from the perpendicular, and then let fall against the second, that and the other four, *c d e f*, will continue stationary; but the last ball *b* will fly off to B, being the same distance as that through which the first ball fell. Here the motion or rather the moving force of the ball *a* is propagated through the whole train to the ball *b*, which finding no resistance is acted on by the whole force. This experiment repeated with any number of balls would

What cause modifies the operation of moving forces?
Illustrate the difference between the effects of elastic and inelastic bodies.
What is the nature and cause of *resiliency?*
How may its existence in *ivory* be made sensible?
Describe the experiments which illustrate the law of collision in elastic bodies.

give the same result. It is proper to observe that in stating the effect of the collision of the balls in these experiments, they are supposed to be perfectly elastic bodies; such however do not exist among the substances with which we are acquainted; the phenomena exhibited by ivory balls would therefore be nearly, but not exactly, such as are stated.

20. The effect of elasticity in modifying the propagation of motion is curiously displayed in those exhibitions of human strength, which have occasionally taken place, and of which remarkable instances are related by some authors. Vopiscus, the Roman historian, mentions a circumstance of this kind, in his Life of Firmus, who, in the reign of Aurelian endeavoured to make himself emperor in Egypt, and who has therefore been reckoned one of the Thirty Tyrants. He was a native of Seleucia, in Syria, who espoused the cause of the famous Zenobia, Queen of Palmyra; and having been taken prisoner, he was executed by order of the emperor Aurelian. The historian says of Firmus, that he was able to bear an anvil on his breast, while others were hammering on it: he lying along, with his body in a curved position. And Beckmann, in his History of Inventions, notices the extraordinary feats of John Charles von Eckeberg, a German, who travelled over Europe about the beginning of the last century. After mentioning other feats, he adds, "But what excited the greatest astonishment was, that he suffered large stones to be broken on his breast with a hammer, or a smith to forge iron on an anvil placed upon it."* A part of the mysterious effect produced in these cases is to be accounted for by the position of the exhibiter, which may be thus described. He must place himself with his shoulders resting on one chair, and his feet upon another, both chairs being fixed so as to yield firm support; and thus his backbone, thighs, and legs would form an arch, of which the chairs would be the abutments. The anvil also must be so large as by its inertia and elasticity, nearly to counterbalance the force of the hammer; and thus the strokes would be scarcely or not at all felt; besides which the elasticity of the man's body, as well as his position, would contribute to his security against the effect of the blows.

Velocity of Moving Bodies.

21. Communication of motion, however rapid, must take up some portion of time; for as there can be no such thing as instantaneous motion, much less can motion be propagated instantaneously from one body to another. Hence motions performed with

What property of matter is assumed in stating these experiments, and how is it to be applied?

What remarkable example of the effect of elasticity does the human body afford?

What explanation can be given of the exploits of Firmus and Eckeberg?

* Hist. of Invent., Eng. Trans. 1797. Vol. iii. p. 203.

great velocity sometimes produce peculiar effects, as may be shown by the following experiments.

EXPERIMENT I.

22. A long hollow stalk or reed, suspended horizontally by two loops of single hairs, may, by a sharp quick stroke at a point nearly in the centre, between the hairs, be cut through, without breaking either of them. The hairs in this case would have been ruptured, if they had partaken of the force applied to the stalk; but the division of the latter being effected before the impulse could be propagated to the hairs, they must consequently remain unbroken.

EXPERIMENT II.

23. A smart blow, with a slight wand, or hollow reed, on the edge of a beer-glass, would break the wand, without injuring the glass.

EXPERIMENT III.

24. A shilling, or any small piece of money, being laid upon a card placed over the mouth of a tumbler glass, and resting upon the rim of the glass, the card may be withdrawn with such speed and dexterity that the piece of money will not be removed laterally, but will drop into the glass.

EXPERIMENT IV.

25. A bullet discharged from a pistol, striking the panel of a door half open, will pass through the board, without moving the door; for the velocity of the bullet will be so great that the aperture is completed in a space of time too limited to admit of the momentum of the moving body being communicated to the substance against which it is impelled.

26. It is an effect of the principle just illustrated, that the iron head of a hammer may be driven down on its wooden handle, by striking the opposite end of the handle against any hard substance with force and speed. In this very simple operation, more easily conceived than described, the motion is propagated so suddenly through the wood that it is over before it can reach the iron head, which therefore, by its own weight, sinks lower on the handle at every blow, which drives the latter up.

27. The velocity of motion is measured by time and space taken conjointly or relatively. Thus, a body moving through a given space, in a certain time, and supposed to pass through every part of that space at a uniform rate, is said to move with a velocity denoted by the ratio of the time to the space; and there-

State the four experiments which exemplify the peculiar effects of rapidly communicated motions.

How do you explain the operation of driving a handle into the eye of a hammer?

How is velocity of motion measured?

How are the relative velocities of different bodies estimated?

fore a uniformly moving body will describe equal spaces in equal times, and different bodies relativo spaces in relative times. Hence a horse that will trot eight miles in an hour, would trot sixteen miles in two hours, and twenty-four miles in three hours, if he could traverse the distance with unabated speed. If in this case the three distances mentioned be considered as three distinct journeys, it will readily be perceived that the horse must have passed through the same distance, in each of the two hours of the second journey, and each of the three hours of the third journey, as in the single hour of the first; and this is what is meant by the statement that equal spaces are passed over in equal times; so that when the distance travelled is doubled or tripled, the time will be doubled or tripled also; and if the distance is reduced to one-half or one-fourth, the time will be reduced in the same proportion. The relative velocities of different bodies must be estimated in a similar manner. A man walking three miles in an hour would require double the time to perform a journey of eighteen miles, that would be taken up by another man running six miles an hour; and a horse galloping twelve miles an hour would complete the journey in one-fourth of the time of the first man, and one-half the time of the second man. The minute-hand of a common clock or watch has twelve times the velocity of the hour-hand, since the former passes through a whole circle, while the latter is passing through the twelfth part of it.

27. The velocity of a uniformly moving body may be discovered by dividing the space passed through by the time consumed: thus, the velocity of a steam-boat, going eighteen miles in two hours, will be found to be nine miles an hour. The velocity being known, the distance passed over in a given time may be discovered, by the contrary operation of multiplying the velocity by the time: thus, the steam-boat, with a velocity of nine miles an hour, will of course run twice nine miles in two hours, and forty-eight times nine miles in forty-eight hours.

Different Kinds of Motion.

28. Motion may be uniform or variable with respect to its rate or relative velocity. The nature of uniform motion has been just pointed out: and that of variable motion will be subsequently investigated. But motion may be different in one case from what it is in others, when considered with regard to the manner in which a body moves: as whether in a straight line, in a circle, or in any other curve. The line described by a body, in passing from one point to another, is called its direction, or line of motion. The direction of a moving body may be either a right line, across a level surface, or plane; a curved line, passing over a similar plane; or a curved line, the different parts of which are not on one plane.

What is the method of discovering the velocity of a uniformly moving body? of computing its distance passed over?

What distinctions of motion are founded on its *direction*?

29. Curvilinear motion is of a more complicated nature than motion in a straight line, the circumstances relating to it therefore cannot be properly explained without a previous investigation of rectilinear motion.

Sir Isaac Newton, in his great work entitled "Principia Philosophiæ Naturalis," "Principles of Natural Philosophy," has laid down three general positions, styled *Laws of Motion*, which have been considered as the foundation of mechanical science. These laws are the following:

I.

"Every body must continue in its state of rest, or of uniform motion in a straight line, unless it is compelled to alter its state of rest or motion, by some force or forces impressed upon it."

II.

"Every change of motion must be proportioned to the impressed force or forces, and must be in the direction of that force."

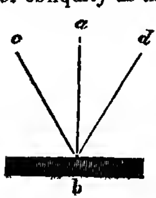
III.

"Action and reaction are always equal and contrary to each other."

30. Both the first and the last of these laws or positions, relating to moving bodies, have been already discussed, and their consequences pointed out: they may therefore be admitted as propositions not requiring further demonstration.

The second law of motion is of the highest importance, as it relates to compound motion, and the direction of a body acted on by two forces in different but not contrary directions. The effect of forces thus applied will be most readily understood after a short explanation of the nature of reflected motion, which affords a familiar example of action and reaction, the subject of the third of the preceding laws.

31. If a cricket-ball, or any similarly shaped elastic body, be dropped perpendicularly on a smooth pavement, it will rebound to a certain point in the same straight line in which it descended; but if it be impelled obliquely against the pavement, it will not rise in a perpendicular line, but in a line having the same degree of obliquity as that in which it struck the pavement.

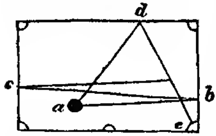


Thus, if the ball were dropped from *a*, to the pavement at *b*, its upward course would be in the same line, *b a*; but if it be thrown in the line *c b*, it will rebound in the line *b d*. In this case the angle formed by the line *c b*, with the line *a b*, is called the "angle of incidence," and that formed by the line *d b*, with the line *a b*, "the angle of reflection;" and it is to be observed that these angles will always be precisely equal. For it signifies not whether the obliquity of the line of incidence be great or small, since the line of reflection will in every

What three *laws of motion* were laid down by Newton? Which of these is of the greatest importance, and why?

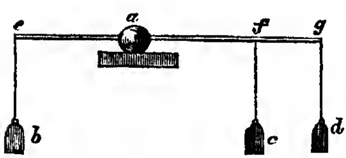
How is the principle of compound and reflected motion illustrated in the motions of cricket and billiard balls?

case have the same obliquity, and consequently form a similar angle with the surface from which the body rebounds.



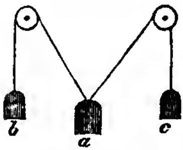
32. Suppose the parallelogram in the margin to represent a billiard-table, if a ball standing on it be impelled in the direction *a b*, it will strike against the end cushion and return in the line *b c*, and either of those lines would form a similar and very acute angle with a line drawn between them parallel to the sides of the table; but if the ball were driven from *a* against the side cushion at *d*, it would return in the corresponding line *d e*.

33. Equal weights, or equal forces of any kind, acting on a body, in a similar manner, but in opposite directions, will keep it in a state of rest or equilibrium, like the scales of a common balance, each loaded with a weight of one pound. But when the arms of a balance are of unequal lengths, as in the steelyard, a small weight fixed at the end of the longest arm will counterpoise a much greater weight at the end of the short arm.



34. Let *a* represent a globe of lead resting on a level surface, and having an iron rod passing exactly through its centre, the extremities of which *e* and *f* are equidistant from the ball; if threads of equal lengths be fixed at those points with hooks at the lower ends for the suspension of weights, the globe and rod will be kept in equilibrium so long as the weights *b* and *c* are equal; but if a longer rod be passed through the ball projecting further from it towards *g* than towards *e*, a smaller weight *d* will then counterbalance the weight *b*, and the relative number of ounces or pounds contained in these weights will always bear certain proportions to the number of inches or feet in the respective parts of the rod *e f*, and *e g*.

Here the equilibrium is maintained by equal forces acting in opposite directions; and the illustration of this simple principle is deserving of attention, as it leads to the consideration of the case of equilibrium maintained by the application of three forces.

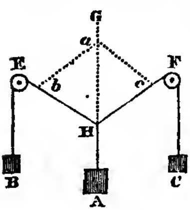


35. In the annexed figure the weight *a* being attached to the centre of a cord passing over two small wheels, and the weights *b* and *c* to either end of the cord, the equilibrium will be maintained only while the central weight counterbalances those at the ends, in order to which, exclusive of the effect of

How may the equilibrium of a body be preserved, and how is this subject exemplified?

How may an equilibrium be maintained by the application of three forces to a flexible cord?

friction, the weight *a* must be less than the sum of the two equal weights *b* and *c* taken together. For if the weight *a* be equal to the sum of *b* and *c*, there can be an equilibrium only when the two ends of the cord which sustain it become perfectly parallel to each other and to the parts which support *b* and *c*. This case is familiarly illustrated by the manner often adopted of suspending lamps from ceilings by means of a weight, to which the two ends of a chain or cord are attached, which having passed over two pullies at the ceiling very near each other, comes down through a hole in the centre of the weight, and receives the lamp at the middle part of the chain. By this means free motion is allowed to the lamp to ascend and descend through a convenient distance, and the equilibrium is maintained in all positions. If the weight *a* be greater than the sum of *b* and *c* the cord will obviously sink in the centre, and the weight *b* and *c* be drawn up to the wheels; and weight added on either side will drag down the cord on the side of the additional load and raise the central and opposite side-weight.



36. Suppose a cord, as in the marginal figure, stretched over the wheels E F, attached to an upright board, and having fixed to its extremities the weights B C. From any part of the cord, between the wheels, as at H, let a weight A be suspended, it will then draw down the cord so as to form an angle, E H F, and the weights will remain in equilibrium. It is obvious that in this case the weight A, acting in the direction H A, will counterbalance the weights B and C, acting in the direction H E and H F, and their joint forces must be equivalent to a force equal to A, acting in the direction H G. To ascertain the relative effect of the weights thus operating, it will be necessary to complete the figure, by drawing on the board the dotted line H G, in the direction of the cord A H; and lines under the cords H E and H F. Then on the line H G mark the point *a*, and H *a* must be supposed to represent as many inches as the number of ounces contained in the weight A. From *a* draw the dotted line *a b*, parallel to H F, and the dotted line *a c*, parallel to H E; then if the diagram were in the proportion just described, the line H *b* would contain as many inches as there were ounces in the weight B; and the line H *c* as many inches as the number of ounces in the weight C. A moment's reflection will show that the relative weights and lengths might consist of any denominations of weight and longitudinal measure; so that feet and pounds, or any greater or smaller denominations might have been substituted for inches and ounces; only in every case the same denomination of longi-

What familiar illustration can be given of an equilibrium of this sort?

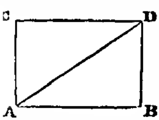
Describe the apparatus for exemplifying the parallelogram of forces.

tudinal measure must be applied to all the lines, and the same denomination of weight to all the gravitating forces.*

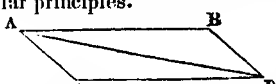
37. The case just considered affords an experimental illustration of what is called the parallelogram of forces, a principle of the utmost importance in mechanics, since it enables us to estimate the joint operation of moving powers, as well as their relative effect or influence.

In the preceding diagram, the parallelogram of forces is represented by the lines *a b*, *b H*, *H c*, and *c a*, and the line *H a*, joining the opposite angles, which is called the diagonal. The sides of the parallelogram, *a b*, and *a c*, will represent the quantity and direction of the two forces acting together, and the diagonal *H a* will denote the equivalent or counterbalancing force. This last force is styled the resultant, and the two forces opposed to it are its components.

38. In the preceding examples, the object has been to show the effect of opposing forces in producing equilibrium; but precisely the same method may be taken to explain the operation of forces applied in different directions, when their effect is to produce motion, instead of restraining it.



If a body A be impelled at the same time by two forces, which would separately cause it to describe the lines A B and A C of the parallelogram A B D C, the body will, by their joint action, describe in the same time the diagonal A D. For if the body had been previously moving with the velocity, and in the direction A B, and had been acted on at A by the force A C, it would have described A D in the same time. So that, whether the forces begin to act simultaneously or successively, their effects may be calculated on similar principles.



39. When the angle at which the different forces meet is very acute, they act with greater power on the moving body; thus, as the angle C A B, made by the directions of the composing forces, decreases, the effect arising from their joint impression will be increased;

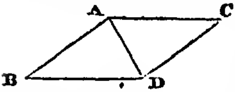
Whence does this principle derive its importance in mechanics?

How is the parallelogram of forces applied to explain the laws of motion?

Under what circumstances will the effects of two forces co-operate in producing motion in the same direction? How may they destroy each other's effects?

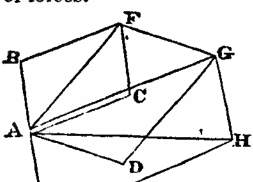
* On this subject, see a description, in the Journal of the Franklin Institute, vol. 3. p. 354, of the tricardo, showing under what circumstances three forces may produce a stable, and in what cases an unstable, equilibrium.—Ed.

and hence the diagonal A D, which expresses that effect, will likewise be increased. Therefore, when the angle C A B vanishes, or in other words, when the sides A C and A B coincide with the diagonal, the joint forces will have their full effect; but this would no longer be a case of the composition of forces, but of the junction or union of two forces.



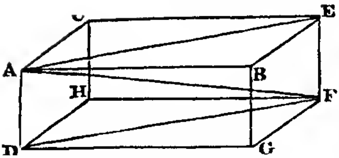
40. When the angle B A C, made by the directions of the two forces, is very obtuse, their effect is diminished, and the diagonal, representing the resultant of the forces, is consequently contracted. It will be obvious, therefore, that when the sides A B and A C meet without forming any angle, the forces will act in opposite directions; and provided they were equal forces they would destroy each other, no motion taking place; but if one force be superior to the other, the body will move on, not in a diagonal line, but in the direction of the greater force.

41. The combined effect of three or more forces acting on a body in different directions, may be discovered by means of the parallelogram of forces; and a single force may be thus assigned which will be the resultant of those forces. This may be done by obtaining first the diagonal representing the resultant of the combination of two forces, and considering that diagonal as the side of a parallelogram, of which a line representing a third force will form one of the other sides, and the parallelogram being completed, the diagonal will be the resultant of the first three forces; and the operation may be extended in the same manner, so as to discover the ultimate resultant of any given number of forces.



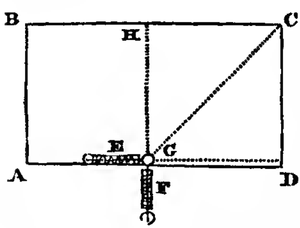
Let the point A be impelled by forces in the directions A B, A C, A D, and A E; then, to find out the resultant of these combined forces, complete the parallelogram C A B F, and the diagonal A F will exhibit the result of the forces, A B and A C. Complete the parallelogram D A F G, and its diagonal A G will denote the result of the three forces A B, A C, and A D. In the same manner, complete the parallelogram E A G H, and the diagonal A H will represent the force compounded of all the four forces, A B, A C, A D, and A E. But the construction may be simplified by merely drawing the lines B F, equal and parallel to A C; F G, corresponding with A D; and G H, bearing the same relation to A E; then, the line joining A and H, which as before will express the resulting force.

How may the combined effect of several forces be determined? Construct and explain the diagram relating to this subject.



42. It may be demonstrated by means of the parallelogram of forces, that from three forces acting in the directions A B, A C, and A D, in the proportions of the length, breadth and depth of a parallelopiped,* will result a motion in the diagonal A F of that parallelopiped; for A B and A C compose A E, and A E and A D compose A F; which last is the resultant of the moving forces in the directions of the three sides of the parallelopiped.

43. The effect of the composition of forces, when a body impelled in different directions takes its course in a diagonal line between the two impelling forces, may be thus experimentally exemplified:



On a billiard-table, A B C D, place a ball at G, equally distant from the side B C, and the end C D, then let two spring guns, capable of communicating equal impulses, be placed so that when the ball is impelled by E, it will move along the side A D, and that when the ball is impelled by F only, it will move in the line G H: then if the ball be struck by both the guns at the same instant, it will be found to move in the diagonal line G C, in the same time in which it would have moved from G to D, impelled by the gun E alone; or from G to H, if acted on only by the gun F. From the observations which have been already made on the relations between the extent of the lines described by moving bodies, and the amount of the forces by which they are impelled, it will be apparent that this experiment may be so modified as to show what would be the direction of the ball, when the impelling forces, or the angles at which they acted, were variously adjusted.

44. The operation of the principle called the composition of forces may be perceived in numerous cases of frequent occurrence. Indeed there are no motions with which we are acquainted that can be considered, strictly speaking, as instances of simple motion; for the effects of gravitation and the diurnal motion of the earth are alone sufficient to occasion some degree of complexity

What will be the direction and amount of a motion produced by three forces proportionate to the length, breadth, and depth of a parallelopiped?

What experimental illustration exemplifies the composition of forces?

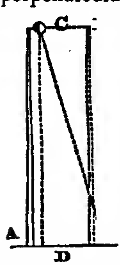
How extensive is the application of this principle?

* See Introduction, 5.

in all motions taking place on the earth's surface. Simple motion therefore is only relative.

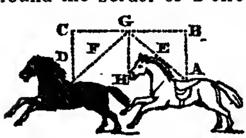
45. Suppose two persons to be seated on the opposite sides of an omnibus, or any other oblong carriage, and to pass a ball forwards and backwards, from one to the other, in a level line. Now, if the carriage were four feet wide, and the ball were passed across that space in precisely the same time that the carriago would be going four feet along an even road, the real motion of the ball through the air would be in a zigzag line.

46. A stone dropped on the deck, from the mast-head of a ship under sail, would be affected by the motion of the vessel, as well as by the force of gravitation, and would therefore fall, not in a perpendicular, but in a diagonal line.



Let A represent the mast, C the stone, D the deck, and the line C E will be the distance that the mast-head will have moved, while the stone would have fallen, by the force of gravity alone, from C to the point under it on the deck; the mast being fixed is carried forward by the ship, and therefore the foot of the mast will have moved equally with the head, and will have reached the point vertically beneath E when the stone touches the deck; the stone will also be found at the foot of the mast, having taken a diagonal direction, in consequence of its being impelled at the same time by the ship's motion and by its own weight. For, if it had not been affected by the former as well as the latter, it would have fallen where the foot of the mast was when it began to fall, and not at the actual foot of the mast.

47. Any one who has witnessed the common feats of equestrian exhibiters at a circus, or elsewhere, may have seen a man leap from the back of a horse over a garter or handkerchief stretched horizontally across the track in which the horse was galloping, round the border of a circular area, and the horse passing under



the garter, the man comes down again on the saddle, after finishing his leap. To do this, it is only necessary for the rider to spring upright from the saddle, on which he was previously standing, and suffer himself to sink by his own weight on the saddle again; for as his body would partake of the motion of the horse, that force would be sufficient to carry him forwards, and his motion in rising, by an impulse which would carry him from A to B if the horse were standing still,

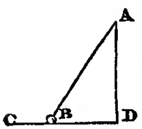
What is the real motion communicated to a body thrown from one side of a carriage to another when in motion?

Illustrate this principle in the falling of a body from the mast-head of a vessel under way?

What enables an equestrian performer, after leaping upward from a horse in motion, to alight again on the saddle?

would be nearly in the line E, while he would descend in the corresponding line F, through the joint effect of the force derived from the horse, and his own weight, the latter of which alone would occasion him to sink in the direction C D, or G H.

48. As it has been observed that all motions are really of a compound nature, resulting in a greater or less degree from combined forces, it may sometimes be requisite to ascertain the separate effects of acting forces; or to determine what portion of any given force acts in some direction different from that in which motion takes place. The operation requisite for this purpose is called the resolution of forces, the object not being as before, to discover the resultant from the combining forces, but to discover one or both of those forces from the resultant.



If a compound force, acting upon a body, produces motion in the direction A B, and it is required to find the part of that force which affects this body in any other direction, as D C; by drawing A D perpendicular to the direction D C, will be found the proportion which the absolute force bears to that part, which acting alone would produce motion in the proposed direction.

49. A boat may be moved across a river by the current passing in a direction parallel to its banks. To effect this the boat must have a rope fastened to it, the other end of which is connected with another rope extended directly across the stream, a noose or ring being fixed to the first or boat-rope, through which the stretched rope is passed in such a manner that the ring may slide freely in either direction. Then the rudder of the boat being properly turned to receive the impulse of the current, it will pass across the river, for the ropes will prevent it from being carried down the stream, while it glides with ease transversely as the ring of the boat-rope slides from one extremity to the other of the extended rope. Part of the force of the current in this case is destroyed, and the remainder is made to produce a motion in a direction different from that in which the water is flowing. The velocity of the current and that of the boat being ascertained, it would be easy to calculate what proportion of the moving force acted on the boat.

50. When the impulse of air or water is employed as a moving power, either can seldom act directly and with full force, some portion being lost, and the effect consequently diminished. A ship sailing with a side wind has the sails set obliquely with respect

By what operation may the separate effects of acting forces be ascertained?

What is the precise object to be discovered in this case? construct and explain the diagram.

How is the resolution of forces applied in the rope ferry? How might we calculate what proportion of the moving force acted on the boat?

What examples are afforded in which the impulse of air and of water produces a resolution of forces? What becomes of the ineffective part of the force in these instances?

to the course pursued; so the vanes of a windmill, and the float-boards of an undershot water-wheel are moved in general by a force applied in a slanting direction. Indeed tho motion of a windmill would be prevented, by setting the surface of the sails perpendicular to the direction of the wind. In these and many other cases, only part of a moving force is brought into action, the other part being dissipated and lost, because it cannot be made to act in the required direction.

Gravitation.

51. Among the causes of motion, or moving forces, there are some, the effects of which are simple and uniform, producing movement in a single direction or straight line, and for a given time, proportioned to the degree of impulse. Others act in more than one direction, but with combined effect, so as still to produce uniform motion. Nature, however, presents to our notice motions which are not uniform, the velocity of the moving body varying in different parts of its course, so that the velocity or rate of motion may gradually increase to a certain point, and be suddenly terminated; or first increase, and then decrease till it ceases altogether. Motion with a perpetually increasing velocity is called accelerated motion. The phenomena of simple and compound rectilineal motions have been already described; but those of accelerated motion, which come next to be considered, cannot be fully understood without a previous acquaintance with the laws of gravitation, with which they are intimately connected. So general indeed is the effect of the property of gravity or weight on all bodies, within the reach of our observation, that its influence is perpetually interfering with our operations and experiments; and hence references have necessarily been made to it in the preceding pages, as in explaining the cause of the decay of motion, and elsewhere; but it will be requisite here to take a more extensive view of the nature and effects of this important principle.

52. Gravitation or Gravity has been noticed in the Introduction, under the appellation of gravitative attraction, as distinguished from cohesive attraction, capillary attraction, magnetic attraction, and other forces which tend to bring bodies into contact. Most of these forces or kinds of attraction are perceived only under particular circumstances; as cohesive attraction, which seems to act on solid and liquid substances alone, and not on gases; and capillary attraction, which only takes place between certain fluids and solids. But the attraction of gravitation differs from other attractive forces in being a common property of all bodies, since every thing to which we can attach the idea of materiality is affected more or less by gravitation.

53. It is by no means inconsistent with this statement that some

What is the distinctive character of variable motion? What is accelerated motion?

How is gravitation distinguished from other species of attraction? How extensive is its influence over material things?

bodies, possessing all the characteristics of solid matter, capable of being seen and felt, yet in certain circumstances, instead of exhibiting the common effect of gravity, in falling towards the earth or pressing on it, display the contrary phenomenon of ascending from it. Thus, smoke will be seen, in some states of the atmosphere, rising in a column to a considerable height. Even solid masses of no small bulk and weight may be made to ascend to a great height, as by means of an air-balloon. But all these and similar phenomena are in fact so many instances of the effect of gravitation; for the ascending bodies are driven upward solely by the force of the medium through which they pass; since the particles of smoke, or the balloon with its car and contents, cannot advance upward in the most minute degree without displacing, or thrusting downward, portions of the atmosphere equal to their own bulk. Hence it will be perceived that aërostatical bodies do not ascend because they possess absolute levity, but simply because, bulk for bulk, they are lighter than the air. A cork or a piece of deal, for the same reason, will float on water, and if pressed down in it will rise again to the surface, by the effect of relative levity.

54. All substances, then, gravitate towards the earth; that is, they have weight, which occasions them to fall to the earth when dropped from a height above it; to rest upon it with a certain degree of pressure, according to circumstances; or if rendered buoyant, to rise in the atmosphere surrounding the earth, till they reach a part of it where it is less dense than near the surface, so that a portion of it, precisely equal to their bulk, would exactly counterpoise them, and there of course they could neither rise nor fall, without an alteration of their own weight taking place. In the case of an air-balloon, the aëronauts have the means for lessening its buoyancy whenever they may find it convenient, by opening a valve, and letting out a part of the gas, or light air, to which it owes its ascending force; thus they can, at any time, render the weight of the whole apparatus much greater than that of an equal bulk of atmospheric air, and then it must fall to the ground. Smoke only remains suspended till its particles unite, and thus becoming heavier than the air, they descend in the form of small flakes of soot, covering with a dingy coat or incrustation all buildings, after a time, in large and populous places.

55. Let us suppose for a moment that while a mass of smoke and an air-balloon were hovering in the air near together, and at

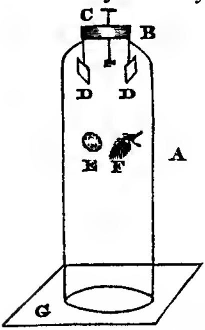
How is the universal prevalence of gravitation to be reconciled with the appearance of light substances rising from the surface of the earth? What is the true explanation of these phenomena?

What expedient enables the aëronaut to descend from a higher to a lower level in the air?

In what manner is smoke finally deposited from the air?

What would be the effect on suddenly removing the air from beneath a mass of smoke and an air-balloon hovering near each other?

precisely the same height, it were possible to withdraw from under them the support of the atmosphere, it will be immediately perceived that they must fall; but probably the young reader will be surprised to learn, that they would not only fall, but likewise that they would both fall through the same space in the same time; so that if their common height had been five hundred feet, the smoke would have reached the surface of the earth at the same instant with the balloon, though the latter might in weight far exceed the other body. It must not be imagined that the circumstance just stated is a mere philosophical conjecture, or that it cannot be confirmed by the test of experiment; for, though it is impossible to annihilate the atmosphere, or effectually remove it from beneath an air-balloon, or any other body suspended in it, yet on a small scale appearances precisely similar to those just described may be easily exhibited.



56. Let A represent a tall bell-glass, open at the bottom, and having the top closed, so as to be air-tight, by a brass cap or cover, B, through which passes the wire C, fitting close, but capable of being turned without admitting the air. The lower end of the wire must be made to support a small stage, the two sides of which, D D, will fall and separate, when the wire is turned in a transverse direction. Then, the stage being fixed, a gold coin and a feather, E and F, or any two small bodies differing greatly in their comparative weight, may be laid on the stage, and the bell-glass, or as it is called, receiver, being placed on the plate, G, of an air-pump, must be exhausted of the air it contained. This being done, if the two bodies E and F are made to fall by turning the wire, it will invariably be found that they will both strike the plate of the air-pump beneath them at the same point of time.

57. The influence of gravitation is not only extended to all bodies on or near the surface of the earth, but likewise, as we have the utmost reason to believe, to all bodies in the universe. This is not the proper place to describe the nature and operation of those forces which regulate the orbits of the moon, the planets, and the comets belonging to the solar system; but it may be here observed that Sir Isaac Newton discovered gravity to be the cause of all the motions of the heavenly bodies; and that the laws of gravitation displayed in the monthly revolution of the Moon round the Earth, the annual circuit of the Earth round the Sun, and the

In what manner can we prove, experimentally, that light and heavy bodies would fall with equal velocity if the air were suddenly annihilated?

How extensively is gravitation applicable to the works of nature?

What discovery did Sir Isaac Newton make on this subject?

corresponding motions of the other planets and their satellites are capable of the strictest mathematical demonstration.

58. Gravitative attraction acts upon all bodies, with forces proportioned to their masses. Thus suppose two bodies so situated as to be wholly exempt from the influence of any attraction except that resulting from their gravitation towards each other, they will then approach with velocities corresponding with their respective forces. If the larger of the two bodies be double the size of the smaller, the former will act with twice the force of the latter; and therefore while the small body will move two feet in consequence of the double power of the larger one, the larger will move but one foot drawn by the single power of the smaller. If the larger body be four times the size of the other it will exert four times as much attractive force, or make the smaller body move with four times as great velocity as it would if the masses of the bodies were equal.

59. Hence it may be regarded as a general law of gravitation, that while the distance between two bodies remains unaltered, they will attract and be attracted by each other, in proportion to their respective masses; and therefore any increase or decrease of the mass must occasion a corresponding increase or decrease of the amount of attractive force, as measured by the velocity.

60. Since gravitative attraction is a common property of all bodies, it may naturally be inquired why all bodies not fastened to the earth's surface do not, by their mutual attraction, come in contact; or by what means the force which they derive from gravitation is prevented from appearing in their relations to each other. A little reflection will show that the cause of this seeming inactivity of bodies at rest is the overpowering influence of the earth's attraction. If a small particle of matter were placed at the surface of a solid sphere or globe of gold, one foot in diameter, its gravitation to the earth would be more than ten millions of times greater than its gravitation to the gold. For the diameter of the earth is nearly forty millions of feet, and the density of gold is nearly four times the medium density of the earth; therefore in a second, the particle would approach the gold less than the ten millioneth part of sixteen feet, a space utterly imperceptible. It is also owing to the immense difference in the mass of the earth and that of any one body on its surface, that the attractive influence of bodies falling towards the earth produces an effect in drawing the earth upwards so insignificant as to be infinitely beyond the reach of our observation.

61. Though we cannot institute direct investigations of the

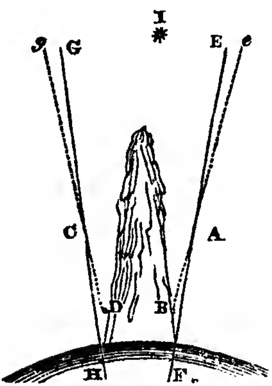
In what proportion does gravitation affect different bodies?

What would be the relative velocities of two unequal bodies actuated solely by each others gravitative attraction? State the general law on this subject.

Why do not all unconfined bodies rush together by their mutual attraction?

Why do not falling bodies draw up the earth instead of descending to its surface?

comparative effect of gravitation, by making experiments on detached masses whose magnitude bears any considerable proportion to that of the earth, yet it may be shown that partially isolated portions of the earth's surface exhibit a sensible degree of gravitative attraction, when small bodies are brought near them. A mountain two miles in height and of an hemispherical figure, rising in a level country, would cause a plummet suspended beside it to deviate one minute of a degree from the perpendicular direction which gravitation towards the earth would otherwise produce. Observations of this nature have been actually made on more than one occasion. The French Academicians, Bouguer, De la Condamine, and others, when employed in measuring a degree of the meridian, in Peru, towards the middle of the last century, having placed their observatories on the north and south sides of the vast mountain of Chimborazo, found that the plummets of their quadrants were deflected towards the mountain. The manner in which these philosophers ascertained the amount of the deflection of their plummets may be thus concisely explained.



Their object being to determine the zenith distance of a star, I, it was necessary to regulate the position of a telescope by means of a quadrant, the plummet of which, instead of hanging in the vertical lines A F, and C H, on the opposite sides of the mountain, were found to take the positions A B, and C D, and thus the star seemed to have the zenith distances *e* I, and *g* I, instead of E I, and G I, which it ought to have had: hence it is obvious that the plummet was drawn aside, by the attractive force of the mountain, from its proper direction perpendicular to the earth's surface, through a space capable of being estimated by the differences perceived in making observations on the star I from the opposite sides of the attracting mass.

62. The phenomena thus observed by the French philosophers having given rise to discussion among men of science in different countries, it was thought desirable to ascertain, by experiments made for that particular purpose, the validity of the cause assigned. King George III. therefore was induced to send the Astronomer Royal, Dr. Maskelyne, to Scotland, in 1772, to make

How may a comparison be made between the whole mass of the earth and an isolated portion projecting above its general level?

Describe and illustrate the experiments which have been instituted on this subject.

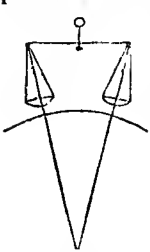
What amount of deviation did Dr. Maskelyne find in his plummet on the sides of Schehallien?

similar experiments on the north and south sides of Schehallien, a lofty and solid mountain in Perthshire, well adapted for the purpose. The deviation towards the mountain on each side, was found, after the most accurate observations, to exoeed seven seconds; thus confirming the inferences of preceding observers, and proving the universal operation of gravitative attraction.

63. The influence of general gravitation was also experimentally demonstrated in a different mannor, by Mr. Henry Cavendish, in 1788.

Two small metallic balls, C and D, were fixed to the opposite ends of a very light deal rod, which was suspended horizontally, at its centre E, by a fine wire. This arm, after oscillating some time horizontally by the twisting and untwisting of the wire, came to rest in a certain position. Two great spherical masses, or globes of lead, A and B, were then brought into such a position, that the attraction of either globe would turn the rod C D on its centre E, in the same direction. By observing the extent of the space through which the end of the rod moved, and the times of the oscillations when the globes were withdrawn, the proportion was discovered between the effect of the elasticity of the wire, and the gravitation of the balls towards the leaden globes; and a medium of all the observations being taken, the experimentalist was enabled to ascertain not only the actual influence of gravitation on terrestrial bodies in general, but likewise its relative influence as depending on the density of the attracting body.

64. As gravitative attraction draws bodies towards the centre of the attracting mass, it might be expected that bodies under the influence of gravitation would diverge somewhat from a line perpendicular to an horizontal plane beneath them.



This indeed is precisely what takes place; and if we imagine a pair of scales, as in the marginal figure, to be formed in such a manner as to bear a certain proportion to a sphere towards the centre of which each scale was attracted, the effect would be obvious. But the magnitudes of any bodies which we can make the subjects of experiment are so extremely inconsiderable when compared with that of the earth, as to render the deviation from the perpendicular, in lines which are actually convergent, quite imperceptible.

65. It must also be considered that though the grand and preponderating force of gravitation is directed towards the centre

Describe the method adopted by Cavendish to demonstrate the influence of gravitation, and the mean density of the earth?

What are the directions in regard to a horizontal plane of two bodies remote from each other, and obeying the force of gravitation?

(and all bodies, like those just mentioned, are attracted towards the earth's centre), yet every particle likewise has an attractive power, therefore the gravitation of bodies on the earth's surface is the effect of the attraction of its entire mass. Hence in the investigation of the phenomena of falling bodies, it may be assumed that all the particles of the same body are attracted in parallel directions, perpendicularly to an horizontal plane; for the spaces through which bodies fall, while under our observation, are not of sufficient extent to render it necessary that any allowance should be made for the effect of direct attraction towards the centre.

66. The slightest observation will enable any one to ascertain that the force of a falling body increases in proportion to the height from which it has fallen. When bodies are precipitated from a great height, they will strike with violence against a resisting surface, or penetrate deeply into a yielding mass. Aërolites or meteoric stones, which are heavy bodies, resembling iron ore, several of which have fallen at different periods, have sometimes been found to sink deeply into the earth; as was observed with regard to a meteoric stone, fifty-six pounds in weight, which fell in a ploughed field in Yorkshire, England, in 1795.

67. Experiments serving to illustrate the effect of accelerated velocity on falling bodies may be made by observing the rebound of an elastic body, when dropped from different heights. A marble or a cricket-ball successively suffered to fall on a pavement, from the respective heights of a foot, a yard, and double or treble that height, would rise higher and higher at each trial, according to the extent of the space through which it had fallen. More exact experiments might be instituted by forming three or four balls of soft wax or moist clay, exactly of equal weight, as one pound each, and letting them drop from different heights on some smooth hard surface; when it would be perceived that each ball was indented or flattened, on the side on which it had fallen, more or less deeply in proportion to the extent of the space it had fallen through.

68. Having thus ascertained that the velocity of a falling body, as denoted by its final force, is increased by the augmentation of the distance passed through, it becomes an interesting speculation to determine what are the relative degrees of velocity produced by given distances of descent. In other words, it is desirable to know whether a body falling through a space during two seconds, or two minutes, would fall as fast again in the second period as t did in the first, or three times as fast, ten times as fast, or in

Whence results the gravitation of bodies on the earth's surface?

How does the force of falling bodies vary with the heights from which they fall?

Exemplify this in the case of aërolites.

What familiar experiments with elastic and with soft bodies prove the relation between velocity and extent of fall?

What relation does the velocity of a falling body actually measure?

what other ratio of acceleration. This is obviously a question of the relation between time and space, for velocity is the measure of that relation. Now the motion produced by gravitative attraction is a continually increasing motion, so that a body under the influence of gravitation will not fall through exactly the same space in any two consecutive periods of time, however inconsiderable. For if we could suppose a single second to be divided into a thousand parts, a falling body would pass through a greater space in the second thousandth part of the second, than in the first thousandth part, and so on in like manner throughout its course. However, in order to find out the rate or ratio of the increasing velocity of falling bodies, it will be sufficient to know what is the distance passed through by a descending body in each succeeding second, minute, hour, or any other equal portion of the time of its whole descent.

69. When we consider the various circumstances which interfere with the motion of falling bodies, some arising from the resistance of the medium through which they pass, and other incidental sources of irregularity, others from the varying force of gravitation itself, at different distances from the centre of attraction, it will be at once perceived that the inquiry before us is surrounded with difficulties. It is no wonder then that very confused and erroneous notions concerning this subject prevailed till a comparatively recent period.

70. Aristotle, whose opinions were long regarded as indisputable, states in his philosophical writings, that if one body has ten times the density of another, it will move with ten times the velocity; and that both bodies being let fall together, the first will fall through ten times the space that the other will in the same time; besides other erroneous doctrines, which were generally received till his theory was overturned by the discoveries of the celebrated Italian philosopher Galileo, towards the end of the sixteenth century. He showed that bodies, under the influence of gravitation alone, would fall through spaces as the squares of the times of descent: that is, that a body, which would fall through one inch in one instant, would fall through four inches in two instants, and nine inches in three instants; for the square of any number is the product of that number multiplied by itself, so four is the square of two, nine the square of three, &c. The principle thus laid down by Galileo, though disputed by some later philosophers,* has not

Will gravitation alone ever produce a uniform velocity of motion? exemplify this point.

How may the rate of increasing velocity be determined?

What prevented the early philosophers from obtaining exact notions of this subject?

What was Aristotle's opinion on the subject of falling bodies?

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* The authority of Galileo was questioned, and different opinions were maintained by philosophers concerning the ratio of the acceleration of

only been triumphantly established as a positive law of nature, with regard to falling bodies, but, as already mentioned, it has been shown by Sir Isaac Newton that it is a general law of nature, extending to the motions of the celestial bodies composing the solar system.

71. In order to apply this principle to the purpose of ascertaining the precise ratio of the accelerating velocity of falling bodies, it is necessary to fix on some measure of time as the unit from which calculations must commence, and to determine what space a body will fall through in that portion of time; and these data being furnished, the application may be readily explained.

72. But before we proceed to the further consideration of the velocity of falling bodies, as the effect of a uniformly accelerating force, it will be proper to observe that it can only be thus strictly estimated with respect to bodies falling through limited spaces, as short distances from the surface of the earth, where the intensity of the gravitating force may be regarded as continuing the same during the whole period of descent. For not only does the velocity of gravitating bodies in descent become accelerated as they approach the centre of attraction, but the intensity of the accelerating force is also continually increasing. And on the contrary, the intensity of the force diminishes as the distance increases. Hence the velocity of a body falling from a great height, as fifty miles from the earth's surface, would increase in a smaller ratio at the beginning of its descent, and in a much greater ratio towards the end of its descent, than that of a body falling through only as many feet.

73. The force of gravitation is to be estimated by the same rule that has been already stated as applicable to the velocity of falling bodies. It increases as the squares of the distances of bodies decrease, and decreases as the squares of their distances increase. Thus, if one body attracts another with a certain force at the distance of one mile, it will attract with four times the force at half a mile, nine times the force at one-third of a mile, and so on in proportion; and on the contrary, it will attract with but one-fourth the force at two miles, one-ninth the force at three miles, one-sixteenth of the force at four miles, and so on as the distance increases. Applying this principle to the gravitative attraction of the earth, it follows that its force must be four times greater at the earth's surface than at double that distance from its centre;

What truth in regard to gravitation was first established by Galileo?
What measure must we adopt previously to applying the principles of gravitation?
Does the rate of acceleration by gravity continue the same at all distances above the surface? State the law applicable to this subject.

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the velocity of falling bodies, even till the time of Newton's discoveries. —Vid. Regis Physic., lib. ii. cap. 23; also, Annotations of Dr. Samuel Clarke, on Rohault's Treatise on Natural Philosophy, a work which was considered as of standard authority in the beginning of the last century

and as the weight of bodies is estimated by the pressure or gravitating force with which they tend towards the earth, a body weighing one pound at the earth's surface would have only one-fourth of that weight, if it could be removed as far from the surface of the earth as the surface is from the centre. And at the distance of the moon from the earth, which is 240,000 miles, the weight or gravitating force of the same body, as affected by the attraction of the earth, would be equal to only the 3600th part of a pound. For reckoning the distance of the earth's surface from its centre to be 4000 miles, that is, half its diameter,* the distance of the moon would be sixty times as great, and the square of that number, or 3600, would, as just stated, indicate the decrease of gravity, at the distance of 240,000 miles from the surface of the earth.

74. This decrease of weight, in proportion to the squares of increasing distances, might in some situations be made the subject of experiment. A ball of iron, weighing a thousand pounds at the level of the sea, would be perceived to have lost two pounds of its weight, as ascertained by a spring balance, if taken to the top of a mountain four miles high. The same body removed from Edinburgh to the north pole would gain the addition of three pounds; and if conveyed to the equator, it would suffer a loss of four pounds and a quarter. To account for the loss of weight in the last-mentioned situation, it must be recollected that the earth is not a perfect sphere, but that its figure is spheroidal, the diameter of the earth from pole to pole being somewhat less than in the line of the equator; the equatorial regions therefore must be more distant from the centre of attraction than the polar regions, and the force of gravitation at the former consequently less than at the latter. Hence the point of greatest attraction must be at either of the poles; for if the iron ball, just mentioned, could be conveyed to the depth of four miles within the bowels of the earth, it would be found to be lighter by one pound than at the surface; since it would be attracted on every side, and the force of gravitation upwards would in some degree counteract the preponderating force with which it would press downwards. If it were possible for the iron ball to reach the centre of the earth, it would necessarily there lose the whole of its weight, for the attraction of gravitation acting equally in every direction, no effect would

How much greater is the force of gravitation at the earth's surface, than at a semi-diameter above it? How much would a pound weigh if carried to the distance of the moon?

How might the decrease of weight in bodies removed to a distance above the surface of the earth be experimentally proved?

How is difference of weights in different latitudes to be explained?

What effect upon its weight would arise from carrying a body far beneath the surface?

What would be the weight of a body carried to the centre of the earth?

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* The mean semi-diameter of the earth may be estimated more exactly at 3956 miles.

be produced, and the ball would be fixed, as if encircled by an infinite number of magnetic points.

75. Connected with this part of the subject there are some curious problems, the solution of which requires mathematical calculations, but the results alone are here introduced, as furnishing interesting illustrations of the power of gravitation.

Suppose the axis of the earth were perforated from pole to pole: a body falling through the perpendicular hole, being attracted on all sides, would be urged downwards only by a predominating force, proportional to its distance from the centre. The velocity acquired at this centre, reckoning the length of the axis 7900 miles, would be equal to 25,834 feet each second. The time of descent would be 1268¼ seconds, or 21′ 8″⅛; and the whole time of passing to the opposite pole 42′ 16″½.*

76. Conceive a body, under the mere influence of terrestrial attraction, to fall from the orbit of the moon to the earth's surface. At the mean distance of sixty semi-diameters of the earth from its surface, the initial force would be diminished 3600 times: with the same continued acceleration, therefore, it would consume a period of 526,578 seconds, or six days, two hours, sixteen minutes, and eighteen seconds, in performing the whole descent. The final velocity, on this supposition being 4680.69 feet each second. Such would be the time of descent under the influence of uniform acceleration; but the time required with an acceleration inversely as the square of the distance from the centre would be only 414,645 seconds, or four days, nine hours, ten minutes, and forty-five seconds. And in this case the final velocity would be 36,256.45 feet, or about seven miles each second. Abstracting, then, from the resistance of the atmosphere, a body propelled directly upwards, with this last velocity of 36,256.45 feet in a second, would mount to the orbit of the moon; but with the addition of one hundred and twentieth part more, or 305 feet to every second, it would reach the sun; and with the further acceleration of less than one foot, amounting to 36,562.43 feet each second, the body would be enabled to continue its flight into the regions of boundless space.†

What would be the velocity and the time of a body descending through a perpendicular hole along the axis to the earth's centre?

How long would it take a body to fall from the moon to the earth? and what would be its velocity on reaching the surface?

With what velocity must a body be shot upwards, in order to pass beyond the solar system.

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* In the hypothetical case here propounded, it must be admitted that the acquired velocity of the body at the centre of the earth would overcome the obstacles to its ascent, and enable it to complete its passage.

† Leslie's Elements of Natural Philosophy, 2nd edit. Edinb. 1829. Vol. i. p. 106, 7.

Accelerated Motion.

77. The increase or acceleration of velocity, from the force of gravitative attraction, has been stated to be as the squares of the numbers representing equal portions of the time during which a body falls. It has heen found convenient to consider the time of descent of falling bodies as divided into seconds, so that if a body, under the influence of gravitation alone, falls one foot in one second, it must fall four feet in two seconds, nine in three seconds, sixteeen in four seconds, and so on, in progression; the squares of the numbers of the seconds showing the number of feet passed through by the falling body at the end of each second. In order to discover the distance passed through in each particular second of the time, it is merely requisite to subtract, from the whole distance completed at the end of that second, the number of feet at the end of the preceding second. Thus, from 4 feet, the distance in two seconds, take 1 foot, the distance in the first second, and 3 the remainder, will be the number of feet passed through in the second second only; from 9, the distance in three seconds, take 4, the preceding distance in the first two seconds, and the remainder 5 will be the distance in the third second; so from 16, the distance in four seconds, the preceding distance of 9 being subtracted, will leave 7, the distance in the fourth second.

78. Gravitation being a continually acting force, a body falling through its influence alone would in every instant of its descent move faster than in the preceding instant, and consequently, at the end of any given time, it would be impelled by a force beyond that which carried it through the preceding space. This force may be estimated in the following manner. Suppose a body, after having fallen during one second, by the impulse of gravitation, to be no longer acted on by an accelerating force, but to continue its motion with the velocity already acquired, describing through the remainder of its descent equal spaces in equal times. In such a case it would be found that the falling body, in every successive second of its descent, after the first, would pass through twice the space through which it had fallen in the first second by the force of gravitation. And the velocity being estimated by the space described uniformly in one second, it follows that the velocity acquired in one second must be equal to double the space through which a body would fall freely by the action of gravity in one second. Since then the velocity increases in the same proportion as the time, it would be twice as great at the end of the second second, as at the end of the first, thrice as great at the end of the third second, and so on.

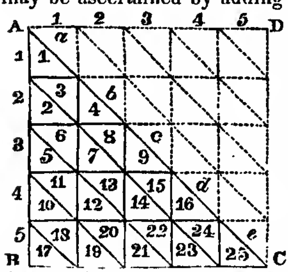
How can we discover the distance passed through in each separate second of the descent of a body? Exemplify this by a particular case.

With what uniform velocity per second would a body move, after having fallen for one second, supposing the force of gravitation to be then suspended?

79. The following table, constructed on the supposition that a body would fall through one foot in the first second of its descent, as furnishing the most simple results, will afford some further illustrations of the positions laid down.

Number of seconds of the period of descent.	Entire space falleo through in feet at the end of each second.	Velocity estimated by feet, at the end of each second.	Space in feet fallen through in each second.
1	1	2	1
2	4	4	3
3	9	6	5
4	16	8	7
5	25	10	9
6	36	12	11
7	49	14	13
8	64	16	15
9	81	18	17
10	100	20	19

80. It will at once appear from the inspection of this table that the time of descent of falling bodies increasing as the numbers 1, 2, 3, &c., and the entire spaces passed through as the squares of those numbers, the augmentation of velocity will be represented by the even numbers, in regular progression, and the spaces passed through in each second by the odd numbers. The sum of the number of feet in the fourth column will of course give the number of feet fallen through in the whole time; and the distance fallen through in any part of the time may be found in the same manner. Thus, $1+3+5$, &c. to 19 inclusive will amount to 100. So the space fallen through in any number of seconds may be ascertained by adding the corresponding numbers in the second and third columns, together with the number representing the space fallen through in the first second of descent. Thus $4+4=8+1=9$; $12+36=48+1=49$; $18+81=99+1=100$. And the same results may be obtained in any similar cases.



81. The nature of accelerating velocity, as exhibited in falling bodies, may, perhaps, be somewhat elucidated by reference to the series of triangles in the annexed diagram. Let the line A B denote the time of the descent of a falling body, divided into equal portions, as seconds; then the small numbered triangles may re-

Explain the relation, as exhibited in the table, between the time, the entire space fallen through, acquired velocity, and space described in each second. What series of numbers represents the augmentation of velocity?

In what geometrical figure may this relation be exhibited?

present the space fallen through, under the influence of gravitation: the number of the triangles in each line showing the number of feet passed through in each second, and the entire number the whole space described in five seconds. By completing the square, as with the dotted lines, it may be perceived how it happens that the velocity, acquired by a falling body at the end of each second, is more than is expended in its passage through the next second; and also it will appear that a body, moving uniformly with the velocity acquired at the end of any given second of time, will describe double the space described in the same time by a body falling under the influence of gravitation alone. For suppose the triangles *a*, *b*, *c*, *d*, *e*, to denote the surplus velocity at the end of each second, which must be sufficient to carry the falling body through one foot, they will, if added successively to the numbered triangles in each line, show the velocity acquired in each succeeding second; and therefore the triangles 17, 18, 19, 20, 21, 22, 23, 24, 25, and *e* will be ten in number, the amount of the velocity acquired at the end of five seconds. Now a body moving with the uniform velocity of ten feet in a second would pass through the distance of fifty feet in five seconds; while a body falling through gravitation only would pass through but twenty-five feet in the same time: and the space described by the uniformly moving body, at the rate of ten feet in a second, may be represented by the square A B C D; while the triangle A B C would represent the space described by a body moving with accelerated velocity, in the same time; and as the square is equal to the doubled triangle, so the former space would be double tho latter.

82. Hence likewise a body moving uniformly, with half the velocity it would acquire at the end of any given time, would pass through a space exactly equal to that which it would describe moving with accelerating velocity during the same time. According to the preceding table, the velocity of a body at the end of ten seconds would be equal to twenty feet; now half that velocity, or ten feet in a second, would carry a body through one hundred feet in ten seconds, which is precisely the space it would have fallen through in that time, by the effect of gravitation.

83. Thus, the velocity acquired at the end of any given time being sufficient to have carried a body twice the distance it would reach with gradually accelerated velocity, it follows that the velocity actually expended in the latter case is only half the velocity that has been acquired; and since the final velocity in each second is represented by a number double that denoting the time, the real amount of accelerating velocity may be expressed by a number equal to the time. Hence as the space fallen through

With what velocity must a body move uniformly, in order to describe a given space in the same time as when uniformly accelerated by gravitation?

How may the real amount of accelerating velocity be expressed? By what product may the *space* be represented?

by a gravitating body is equal to the square of the time, that is the number representing the time multiplied by itself, so the time and the velocity being equal, the space must be as the square of the velocity, or as the time multiplied by the velocity.

84. We have already taken occasion to observe that the force of gravitation varies at different distances from the centre of attraction; and hence the absolute effect of gravitative influence must vary also. The consequence of this principle, as exemplified in the augmentation or reduction of the weight of bodies in different situations, has been pointed out. And since bodies in motion are acted on by gravitation in the same manner as bodies at rest, it follows that falling bodies will describe greater spaces in equal times, according to the increased intensity of gravitation, as occasioned by the diminution of the distance through which it acts.

85. In order therefore to discover by experiment the force of gravitation, as measured by the space through which a body would fall, in a given time, as one second, we must know what is the distance of the gravitating body from the centre of attraction. If, as already remarked, the earth were a perfect sphere, every part of its surface would be equidistant from its centre; but, since it is an oblate spheroid, or globe flattened at the poles, the attraction must there be strongest, and must decrease in the intensity of its force, in the direction of a line from either of the poles to the equator. Such a line would be a meridian of longitude, and the degrees of latitude measured on it would be so many points at which the intensity of gravitation was progressively diminishing.

86. Hence, in experiments made to ascertain directly the amount of gravitative force as measured by the space a body would fall through in one second of time, regard must be had to the latitude of the place where the experiment might be made, and if the utmost accuracy were required, the height of the spot above the level of the sea must also be taken into the account. These observations will be sufficient to show that no small degree of skill and attention would be requisite in order to ensure the perfect exactness of such experiments. Instead therefore of pursuing this train of investigation further at present, we shall proceed to state that numerous and very accurate experiments have been made, whence it appears that in the latitude of London, which is near the level of the sea, a heavy body falls, from the action of gravity, in the first second of its descent, through the space of sixteen feet and one inch, or 193 inches.

87. In making calculations relative to the phenomena of falling bodies, when extreme accuracy is not required, the space passed

What will enable us to discover by experiment the force of gravitation?

How does the figure of the earth affect its force of attraction at the different parts of its surface? Through what space will a body fall in the first second in the latitude of London?

What may generally be assumed for the space described in one second by a body falling freely?

through in one second of time may be estimated at 16 feet; and taking this as the common multiple of distances and velocities, a table similar to that already given may be constructed, by means of which the spaces fallen through in any given time may be ascertained with sufficient exactness. The following short specimen of such a table may be easily extended by the young student, so as to afford data for the resolution of several interesting questions.

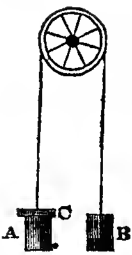
Seconds of descent.	Feet passed through at the end of each second.	Final velocity in each second.	Feet passed through in each second.
1	16	32	16
2	64	64	48
3	144	96	80
4	256	128	112
5	400	160	144

88. Suppose now we wish to discover the height of an eminence, or the depth of a well; by dropping a leaden bullet from the top of either, and observing how many seconds elapsed before it reached the bottom, a table like the above would show by inspection how many feet the space amounted to in either case. No notice, however, is here taken of the resistance of the air, which would greatly affect the motion of bodies falling from a considerable height. Several years ago a man dropped from the balcony of the Monument, near London Bridge, a height of about 200 feet: he would therefore have fallen to the pavement below in nearly three seconds and a half, but for the resistance of the atmosphere; notwithstanding which he must have been whirled downwards with a velocity, which perhaps rendered the miserable being insensible of the appalling catastrophe that awaited him. Sometimes aërolites have exploded in the air, and fallen in showers of meteoric stones, as happened near Sienna, in Italy, in 1794; and at L'Aigle, in France, in 1803. If the moment of such an explosion could be observed, and also that at which the stones, or any one of them, came to the ground, the height at which the phenomenon took place might be estimated with tolerable accuracy.

89. The obstacles which occur in the experimental investigation of the laws of gravitation are partly owing to the very extensive space that would be required for direct experiments on falling bodies, even for a few seconds; and to these would be added the variable effect of atmospheric pressure against bodies moving with great velocity. The consideration of these difficulties led Mr. George Attwood, an ingenious philosopher who died in the early part of the present century, to contrive a machine in which the influence of gravitative force might be moderated without destroying its characteristic efficiency, in the production of an accelerated

How might the height of an exploding meteor be estimated?

What obstacles occur in the direct experimental investigation of the laws of falling bodies?



motion. This piece of machinery was very elaborately constructed, and some parts of it could not be correctly described without entering into extensive details, and giving delineations on a large scale; but the principle on which it acted may be concisely explained. Equal weights A and B, being suspended by a fine silken cord, passing over a wheel moving with the least possible degree of friction; then by adding a certain quantity to one of the weights, as by placing on it a small bar C, descending motion may be produced, differing in intensity from that caused by the unrestrained power of gravitation, but obeying the same law of accelerating velocity; so that, though the loaded weight might be made to descend only one inch in one second, its continued motion would be found to proceed in the regular ratio of the squares of the times of descent.

90. It might be imagined, that as the large weights counterbalance each other, the small bar ought to descend as freely as if they were removed; but the gravitating force expended in producing motion is partly consumed in overcoming the inertia of the large weigh s, and therefore the portion of it which acts as a moving power will bear the same proportion to the whole force, as the weight of the bar alone bears to the entire moving mass, for it is expended in drawing down the loaded weight A on one side, and raising the weight B on the other side, at the same time. Thus if the weights were two pounds each, and the bar weighed but half a pound, the force expended would be but one-ninth part of the whole force; and the loaded weight A would descend but one-ninth part of sixteen feet in the first second of time, and with the same reduced velocity, as the squares of the times, throughout its descent. By means of this machine a variety of most interesting and important experiments may be performed, and the laws of gravitation satisfactorily demonstrated.

91. Bodies projected directly upwards will be influenced by gravitation in their ascent as well as in their descent; but its force must be calculated inversely, producing continually retarded motion while they are rising, and continually increasing motion during their fall. So that a body propelled perpendicularly through the air, leaving out of the question the resistance of the medium through which it passed, would rise to a height exactly equal to that from which it must have fallen to acquire a final velocity the same as it had at the first instant of its ascent. And the velocity would be the same in the corresponding parts of the ascent and descent. The time likewise which the propelled body required to attain its utmost height would be just equal to that during

Describe the principle of Attwood's machine. What portion of the gravitating force of the bar added to one of his equal weights is employed in producing motion?

What laws of motion apply to bodies projected directly upwards?

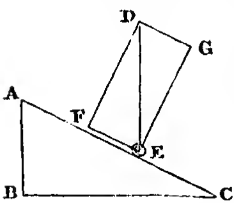
What relation exists between the times of their ascent and descent?

which it would be falling to the ground. Hence the laws which regulate uniformly accelerated velocities will apply equally to uniformly retarded velocities: that is, the velocity lost in any given time, by the influence of a uniformly retarding force, will be as the time; the space passed through as the square of the time, or the square of the velocity; and so on, as in the case of accelerating forces.

Motion of Bodies on inclined Planes and Curves.

92. Among the varieties of accelerated motion depending on the induence of gravitation, that of bodies passing along inclined planes requires to be noticed, as exhibiting the modified effect of a most extensively acting force. When pressure is applied in a vertical direction to a body supported by a horizontal plane, it is manifest that no motion can ensue; and the force of gravitation thus acting can be measured only by the direct weight of the body so situated. But if the plane surface on which the body rests be inclined in any degree, the efficient weight will be proportionally diminished; and if the inclination of the plane be sufficient to enable the body to overcome the resistance to its motion arising from friction and similar causes, the body will move down the plane with a velocity so much the greater as the surface over which it moves approaches to a vertical direction. The motion in this case will be a continually accelerated motion, differing in degree of relative velocity from that caused by the direct influence of gravitation, but subject to the same law of acceleration.

93. In order to estimate the force with which bodies are impelled down inclined planes, we omit for the present all consideration of the resistance occasioned by friction; and therefore suppose a plane to have a perfectly smooth surface, and the figure of the moving body to be globular, and of the same density in every part, so as to be capable of motion in any direction.



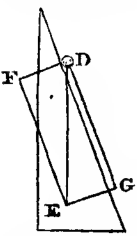
94. Let A C represent the declivity of an inclined plane, A B its perpendicular height, and D E the absolute weight of an ivory ball on its surface; now this weight, by the parallelogram of forces, will be found to act in two directions; D F, or G E, denoting the direct pressure perpendicular to the declivity of the plane, and D G, or F E, in the direction of that declivity: the former force it is

How can the force of gravitation in a body pressing a horizontal plane be measured? What effect on the pressure of the plane will result from its becoming inclined? When will motion commence on the inclined plane?

Of what nature will be the motion over the inclined plane?

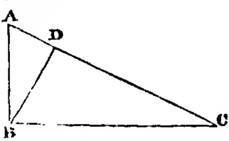
What circumstances are we to omit in first estimating the force of motion on inclined planes? Describe the diagram relating to this subject.

obvious will be destroyed by the resistance of the plane, and the ball will consequently move down the plane with a force bearing the same relation to the force of gravity that D G does to D E, that is, it would move down the plane through a space equal to D G, while it would fall through a space equal to D E by the force of gravitation.



95. Whatever may be the declivity or inclination of the plane, the force of a body moving down it may be estimated on the same principle. Thus suppose the obliquity of the plane to be very considerable, as represented in the margin, the line D G would be nearly equal to D E; and the force of the body moving on such a plane would manifestly be little inferior to that of the same body falling freely.

As the force of a body moving on an inclined plane is less than that of a body moving by the influence of gravitation, its final velocity in a given time must also be less; and the distance through which it must move on a declivity to acquire a certain final velocity must be greater than that through which it must fall freely by the effect of gravity to acquire the same velocity.



96. It may be demonstrated that a body moving down any inclined plano will acquire the same final velocity, in passing from A to C, that it would have gained in falling through the relative distance A B. For let A D be the space through which the body would move down the plane in the same time that it would fall from A to B, it follows that, in order to acquire the same velocity that it would gain by falling from A to B, it must pass through a space bearing the same proportion to A B that A B does to A D; and as the triangles A D B and A B C are similar, their corresponding sides must have the same relations to each other; therefore A D will be to A B, as A B to A C. Hence the proposition will universally hold good, that a body rolling down an inclined plane of any extent or obliquity, but for the effect of friction or similar causes, would acquire the same final velocity, as if it had fallen directly through a space equal to the perpendicular height of the summit of the plane.

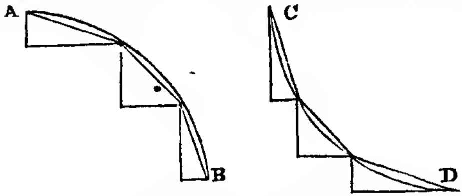
97. Bodies moving on curved surfaces would not exhibit uniformly accelerated velocity, like those moving on inclined planes;

What relation will the final velocity of a body moving on an inclined plane, bear to that which it would acquire in falling perpendicularly through the same distance?

What relation will the velocity of a body falling freely, and of one descending an inclined plane, bear to the length and height of the plane?

With what sort of velocities will a body move down a curved surface? Why would not the motion be uniformly accelerated?

for the resistance occasioned by the peculiar form of the curve in which any such body might move would be continually changing, and the result of that resistance would be a consequent change in both the velocity and the direction of the moving body. Some idea of the nature of this perpetual change may be obtained from considering what would be the effect of presenting to a moving



body a succession of inclined planes, either ascending or descending, the outline of which would form a rude resemblance to a curved surface. From the mere inspection of the preceding figures, it may be comprehended that a body passing over a convex surface, as from A to B, would encounter a perpetually diminishing resistance; and in passing over a concave surface, as from C to D, the resistance would progressively increase. For in the former instance, the effect would be as if the moving body rolled down a number of declivities, each one more oblique than the preceding; and in the latter, it would be as if the body passed over a series of declivities, each of which approached nearer than the preceding to the figure of a horizontal plane.

98. Having thus endeavoured to explain the manner in which curvilinear motions are produced by the constant action of variable forces, we can now proceed to investigate the phenomena of curvilinear motions in general. When a body moves through an entire circle, with uniform velocity, as it must be impelled by forces continually varying in intensity and direction, those variations must be supposed to take place momentarily, or in inconceivably minute portions of time and space. So that such a body might be considered as moving in the circumference of a polygon having an infinite number of sides.

99. In the case of a body moving over a curved surface and in contact with it, there must be a certain pressure of the body on the surface over which it passes, and a corresponding resistance, or pressure on the body, in every instant of its progress. Now this pressure shows the degree of force to which the continual variation of direction, or deflection of the moving body is to be attributed. Suppose a leaden bullet, or a billiard-ball to be made to move round within a hoop laid flat on a table or any level surface, it would obviously press against the inside of the hoop, thus ma-

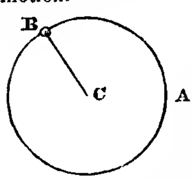
How are the forces which impel a revolving body supposed to vary?
Into what figure may we conceive the circle to be resolved?
How would a body moving within a curved surface be affected by it?

nifesting a constant tendency to escape from the circle in which it was moving, and only withheld by the counterpressure, or resistance of the hoop. If then the hoop were suddenly lifted while the ball was passed round within it, the circular motion would no longer be continued; but the ball would fly off in a right line from the point where it was set at liberty. The force operating on the moving body in this case would be precisely similar to that which would propel forwards a stone discharged from a sling, on letting go the cord which retained it during the previous circular motion or whirling, whence it would acquire its subsequent velocity.

100. The forces which act on bodies revolving in circles or other orbits may be regarded as antagonist powers, one of which perpetually impels the moving body in a right line from the centre of motion, and the other draws it towards that centre; and by the joint action of these forces curvilinear motion is produced. The former, or the repellant power, is named centrifugal force, or force causing bodies to fly from a centre; and the latter is styled centripetal force, or that which attracts moving bodies towards the centre of motion.

101. These opposing forces have also received the common appellation of central forces. It may be here observed that the line in which a body will move, on escaping from the circle around which it must have been previously whirled, will always form a tangent to that circle, or in other words, it will extend in a direction perpendicular to another line drawn from the centre of the circle to the point of escape. Hence this force has been sometimes called a tangential force; but its usual appellation is that of centrifugal force.

102. These forces must necessarily differ in degree according to circumstances,—such as the mass of the moving body, the extent of the circle in which it may move, and the velocity of its motion.



Thus a ball, B, of two pounds weight, would require a greater centrifugal force to make it revolve round the circle A, in any given time, than another ball weighing only one pound. The extent of a circle is to be estimated by its radius, or the line C B, passing from its centre to some point in its circumference, and consequently always equal to half the diameter. Now the centrifugal force or pres-

What line would such a body describe, if suddenly relieved from the confinement of the curved surface?

How may we explain the motion of a stone discharged from a sling?

What is meant by the terms *centrifugal* and *centripetal*, as applied to forces? What common appellation is applied to them? When a body escapes from the influence of its centripetal force, what will be the line of its subsequent path? What is signified by the term *tangential force?*

By what circumstances are central forces caused to vary their intensity? Exemplify the principles applicable to this variation.

sure must increase, as the radius of the curve in which a body moves increases. In a circle the same radius will apply to every part; but if a body should move in any other curve, as an ellipse, the degree of curvature, and consequently the length of the radius, will differ in different parts. Hence the expression, radius of curvature, has been used to denote the line which may be drawn from the centre of motion to any given point of the curve described by a revolving body. The velocity of revolving bodies may be estimated by the actual space passed through in a given time, or by reference to the time in which any such body would pass from one point in the circuit in which it moved to another point. These distances, being measured by the angle formed by lines drawn from the centre of motion to the points just mentioned, the velocity indicated may be styled the angular velocity of the moving body.

103. The amount of centrifugal force in different circumstances may be experimentally determined by means of a machine called a whirling table, which is so constructed that different weights may be whirled at any given distance from the centre of motion, and with any required degrees of velocity; and the measure of the centrifugal force expended is obtained by causing the revolving weights, by their rotatory motion, to draw up other weights, which are suspended freely; and thus the effect of centrifugal force may be ascertained in a satisfactory manner. From the results of experiments with the whirling table, it appears, that the centrifugal force will increase as the mass of the moving body increases; that the centrifugal force will be doubled, other circumstances remaining the same, if the radius or curvature be doubled; that if the radius of curvature remain the same, and the angular velocity be doubled, the centrifugal force will be quadrupled; and that if equal masses be made to revolve within circles, the radii of which are as 2 to 3, and with angular velocities as 1 to 2, the centrifugal force will be as 2 to 12, or as 1 to 6. Hence it appears that the centrifugal force increases in direct proportion to the mass of the moving body, and to the distance from the centre of motion, and also as the square of the angular velocity. Thus:—the radius of the circle being 2—the angular velocity 1, the square of which is 1—the centrifugal force will be the product, $2\times1=2$; the radius of the circle being 3—the angular velocity 2, the square of which is 4—the centrifugal force will be the product, $3\times4=12$; thus, as above, the centrifugal force in the different cases would be as 2 to 12.

What is meant by radius of curvature?

In how many ways may the velocity of a revolving body be estimated? What is meant by *angular velocity?*

What apparatus is employed to demonstrate the laws of centrifugal forces?

What relation have these forces to the masses of the revolving bodies? What relation to the radius of curvature? What to the angular velocity?

104. In order to obtain the amount of centrifugal force at any given point, the square of the number of feet expressing the angular velocity in one second of time must be divided by the number of feet denoting the radius of curvature, and the quotient will give the centrifugal force, as estimated by the number of feet a body impelled by it would describe in one second. Thus, a sling, two feet long, circling vertically, with the velocity of eight feet each second, would communicate to a stone a centrifugal force equal to thirty-two feet in a second, which would be the final velocity of a body falling during one second, and the centrifugal force therefore would be just sufficient to counteract the influence of gravitation, and enable the sling to support its load. If the motion of the sling were accelerated so as to perform a complete revolution in one second, the tension of the string would uphold the stone with a force 2½ times greater than the attraction of gravitation.

105. An amusing experiment, illustrative of the influence of centrifugal force in overcoming that of gravitation, may be performed by placing a tumbler filled with water, in a sling, or fixing it upright in the bottom of a net, when it may be whirled round with such velocity that not a drop of the water will be spilled, though the mouth of the glass will be turned downwards during a part of each revolution.

106. The centrifugal force at the equator may be computed by taking the time of one diurnal revolution=86,164 seconds, the equatorial radius of the earth=20,921,185 feet, and the ratio of the earth's circumference to its diameter=3.14159:1. Then $4\times3.14159^2\times20,921,185\div86,164^2=0.1,112,259$, which is the centrifugal force at the equator. Now as the actual force of gravitation, determined by experiments, the nature of which will be subsequently described, is, 32.08818; and therefore, if the earth were at rest, it would be $32.08818+0.1,112,259=32.1,994,059$, it follows that the centrifugal force at the equator is to the force of gravity in the proportion of the numbers 0.1,112,259 to 32.1,994,059, or nearly as 1 to 289. So that the force of gravitation is 289 times greater than the centrifugal force, at those parts of the earth's surface where the action of the latter is most powerful.

107. Now since 289 is the square of 17, it will follow that if the diurnal revolution of the earth had been completed in one-seventeenth part of the time, which it now takes up; that is, had

How may we obtain the amount of centrifugal force at any given point? How may we compare centrifugal force with that of gravitation?
How may it be familiarly shown, that this force is often superior to that of gravitation?
How may we compute the centrifugal force of the earth at the equator?
What is the actual force of gravitation there, as determined by experiment? What is the amount of centrifugal force, and by how many times does the former exceed the latter?
How much must the velocity of the earth's revolution be increased, in order that bodies at the equator should lose all their weight?

the earth revolved on her axis in eighty-four minutes, instead of nearly twenty-four hours, the centrifugal force would have counteracted that of gravitation, and all bodies would have been absolutely destitute of weight; and if the centrifugal force were further augmented, the earth revolving in less time than eighty-four minutes, gravitation would be completely overpowered, and all fluids and loose substances near the equinoctial line would fly off from the surface.

108. Among the abundant examples of the effects of centrifugal forces that might easily be adduced, a few may here be noticed, in addition to those already given. The astonishing power of this force, even when exerted on a small scale, appears from its destructive influence on hard solid bodies; as when grindstones are whirled about with extraordinary velocity in our manufactories, they will sometimes split, and pieces fly off with amazing force. The more regulated, but no less powerful operation of centrifugal force may be observed in some parts of the machinery employed in certain branches of the arts: as in the fly-wheel which regulates the motion of a steam-engine, and in the coining-press; but these and other modifications of mechanical power will be noticed elsewhere. Semifluid and soft but tenacious substances, under the influence of centrifugal force, assume in a greater or less degree the form of a compressed globe; and thus a rudely-shaped ball of clay, placed on a potter's wheel, with the assistance of gentle pressure while in the state of revolution, gradually acquires a symmetrical form; and globular glass vessels owe their figure to the analogous manipulations of the glass-blower. Liquids exposed to a whirling motion are similarly affected; as may be perceived if a glass of water be suspended by threads, and made to turn with great velocity by the twisting and untwisting of the threads, when the water would sink in the centre, and rise on the sides so as to escape in part over the edge of the glass. In all cases centrifugal force tends to make bodies under its influence recede from a central point, and when it acts in conjunction with a centripetal force, the effect will be revolving motion, whether those powers be exerted in keeping a peg-top, or a teetotum spinning on a floor or table, for a few minutes; or in causing the vast globe which we inhabit to revolve with undiminished energy through countless ages.

Oscillation of the Pendulum.

109. Oscillation or vibration is a peculiar kind of curvilinear motion, depending on the influence of gravitative attraction, and it not only affords the means for ascertaining the variation of the force of gravitation in different latitudes, but likewise furnishes

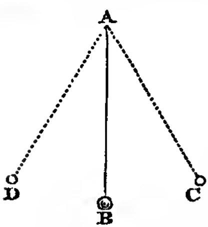
Give some examples of the effects observed to result from centrifugal force.

What is meant by oscillation?

To what purposes in science and arts is it applicable?

the most accurate method for measuring time, and leads to various important results in the investigation of many natural phenomena.

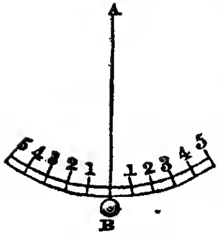
110. When any heavy body is suspended by a string or small wire, it will take a direction in a line vertical to that point of the earth's surface over which it hangs, as in the case of the plumb-line of a mason's level when placed on a horizontal plane. Now the laws of oscillation are those which would regulate the motion of a body thus suspended, if drawn aside from the vertical line in which it would rest, and then let go and suffered to oscillate or swing forwards and backwards undisturbed. In treating this subject it will be most convenient to consider the phenomena of oscillatory motion simply and independently of the effects of the resistance of the air, the friction of the suspending line on the point of suspension, and the varying extension of that line; all which it is obvious would affect the results of actual experiments, and would therefore require attention in making calculations founded on them.



111. Suppose A B to represent a pendulum at rest in the vertical position, if it be then drawn from B to C and let fall, it will return to B, with an accelerated motion, which, however, will not be uniformly accelerated, since it must depend partly on the gravitation of the pendulum towards the earth, which acting alone would cause it to fall perpendicularly from the point C, but which being modified by the tension of the line, it is forced to describe the arc C B. Now at B the direct power of gravitation will be not merely modified but destroyed, for the line being stretched to its full extent would prevent any further descending motion; but when arrived at B, the pendulum would have acquired a certain degree of velocity during its previous descent, which would be just sufficient to overcome the force of gravity tending to retain it at the point B, and make it move forward from that point to D, with a retarding velocity, which would there be entirely expended; and since the pendulum at D would be in a situation exactly corresponding with that in which it was placed at C, it must again describe the same arc D B C, but in a retrograde direction, first with a gradually accelerated velocity, and then with a velocity progressively retarded. Thus, but for the obstacles already mentioned, and the wear and tear of materials, a pendulum, once put in a state of vibration, would go on regularly oscillating for ever.

112. The vibrations of any one pendulum will be described in equal times whatever be the extent of the arc through which it moves, provided that arc do not exceed a certain limit.

What circumstances affect the results of experiments on oscillation? What forces combine to produce oscillatory motion? What causes the ascending part of an oscillation?



Thus when the vibration of a pendulum is progressively weakened by the resistance of the air, every succeeding arc passed through will be less than the foregoing; and yet it will be found that though the pendulum moves slower and slower continually, there will be but little difference in the time taken up by the ball in moving from 5 to 5, 4 to 4, &c., on each side of the line A B, till it stops entirely. It is this remarkable property of the pendulum that makes it so useful as a measure of time; and clocks, or time-keepers, regulated by a pendulum, are nothing more than trains of wheel-work kept in motion by weights, and so arranged as to register the beats of pendulums which oscillate seconds. This equality of vibration of bodies in certain curves was discovered by Galileo, whose attention is said to have been excited by remarking the motion of a chandelier hanging from the ceiling of a church at Pisa; for, noticing that it moved with uniformity as to time, independent of the space passed through, he was induced to make experiments, which established what has been termed the law of Isochronism, or equality of time.*

113. As it is only when oscillating in very small arcs of circles that pendulums preserve this regularity of vibration, it became a subject of inquiry among philosophers whether a curve could not be found in which the isochronism of a pendulum would be perfect; and such a curve was discovered by the celebrated Dutch mathematician, Huygens, the contemporary of Newton. It has been named a cycloid,† and from its property an isochronal curve, and it differs little from an arc of a circle, except in rising somewhat more abruptly at each extremity. But it is the less necessary to enter into any further description of its nature and properties, as it has been found after all to be less adapted for practical purposes than small circular arcs, in which therefore the pendulums of time-keepers are made to oscillate.

114. The vibrating weight of a pendulum does not influence its motion; for whether a great or a small weight be affixed to a vibrating line, its oscillations will be similar, provided the length of the line, measured from the point of suspension to the centre of oscillation, remains the same. Sir Isaac Newton made experi-

What is meant by the isochronism of oscillations? By whom was this character discovered?

In what form of curve must oscillations be performed, in order to be isochronous?

What influence has the weight of a pendulum on the time of its oscillation?

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* From the Greek Ισος, equal, and Χρονος, time.

† From the Greek Κυκλος, a circle, and Ειδος, a resemblance.

ments on a great variety of substances, as metals, stones, woods, salts, portions of flesh, &c., whence he ascertained that how greatly soever they might differ in weight, the addition of any of them to a pendulum would not interfere with its rate of oscillation, so long as its length remained unaltered. Thus, as heavy bodies and light ones would fall to the earth, through a given space, in the same time, but for the resistance of the air, so they would be found to vibrate in equal times at the end of a line of a given length, provided atmospherical resistance could be made to act on them in the same manner, or be entirely excluded, as by inclosing the vibrating bodies in an exhausted receiver.

115. It is on the length of the pendulum that the rate of oscillation principally depends; that is, the greater the distance between the point of suspension and the point of oscillation, the longer will be the period of each vibration; and on the contrary, the shorter that distance, the quicker will the vibrations take place. Now, as gravitation is the power on which oscillatory motion depends, so the same law that regulates its operation on falling bodies is observable in its action on oscillating bodies; for as the intensity of gravitative force decreases as the squares of the increasing distances of bodies, thus the time of a vibration will increase as the square root of the length of the pendulum, or the distance from the point of suspension to the point of oscillation, increases. If then a pendulum 1 yard in length, would make one vibration in one second, a pendulum $\frac{1}{4}$ of a yard long would vibrate half seconds, one 4 yards long, would vibrate once in two seconds, one 9 yards long, in three seconds, and so on; for $\frac{1}{2}$ is the square root of $\frac{1}{4}$, 2 of 4, 3 of 9, &c.

116. But in order to obtain the absolute length of a pendulum that would swing seconds, it is necessary to take into consideration the intensity of gravitation, which, as already stated, varies at different parts of the earth's surface, depending on their relative distance from the centre of gravitative attraction. The greater the intensity of gravitation at any place, so much the quicker will be the vibrations of a pendulum of a given length: so that a pendulum which would oscillate seconds at London would perform each of its oscillations in somewhat less than a second, if it could be removed to the north pole; and on the contrary, would take up more than a second in one vibration under the equinoctial line.

117. The intensity of gravitation at any given point of the earth's surface thus corresponding with the vibrations of a pendulum of a given length, it follows that if the intensity of gravita-

What resemblance in this respect has the pendulum to bodies falling freely?

On what circumstance in a pendulum does the time of its oscillations depend? Between what two points is the true length of a pendulum to be taken? Illustrate the law of its motion by an example.

What local circumstance must be taken into view in obtaining the absolute length of a pendulum?

tion at any place, as estimated by the space which a body falling freely would describe in any time, as one second, be known, the length of a pendulum, which would vibrate seconds at that place, may be ascertained by computation. For since the time of vibration is to the time of descent through half the length of the pendulum, as the circumference of a circle to its diameter, that is, as 3.14159 to 1, let the time of vibration be 1 second, then the length of the pendulum may be thus found: the time of descent of a body during 1 second, in the latitude of London, by the influence of gravitation, has been already stated to be about 16 1-12 feet, or 193 inches; and since the spaces of descent are as the squares of the times, therefore $\overline{3.14159}^2 : 1^2 :: 193 : 19.0625 = 19\ 1\text{-}16$ = half the length of the pendulum, which must therefore be $19\ 1\text{-}16 \times 2 = 39\frac{1}{8}$ inches.

118. In order to determine the length of a second's pendulum by experiment, a pendulum of a known length must be made to oscillate for a certain time, as one hour; then the square root of its length will be to the square root of the length of the required pendulum, inversely, as the number of vibrations performed in an hour, by the pendulum which has been the subject of the experiment, to the number of seconds in one hour. Thus, if in any latitude it could be ascertained that a pendulum 9 yards in length oscillated 1200 times in an hour, then as the number of oscillations, 1200, to the square root of the pendulum, 3, the square root of 9, so inversely would 3600, the number of oscillations required to be performed by the seconds pendulum, be to the square root of its length: that is, as $3600 : 3 :: 1200 : 1$; since $1200 \times 3 \div 3600 = 1$, the square of which would be 1; therefore a pendulum 1 yard long would swing seconds in any place where a pendulum 9 yards in length would make but 1200 vibrations in an hour.

119. It will be obvious, from what has been already stated, relative to the effect of friction, atmospheric resistance, and the extensibility of the line of suspension of a pendulum, that a multitude of precautions would be requisite in making direct experiments on the lengths of pendulums, with reference to the times of vibration at any given place. Dr. Halley, in the early part of the last century, estimated the length of a second's pendulum at 39.125 inches, $= 39\frac{1}{8}$ inches; and that estimate has been generally adopted, as sufficiently correct for practical purposes. From the most recent and accurate researches of men of science, it appears that the length of a pendulum which oscillates seconds, *in vacuo*, at the mean temperature of 62 degrees of Fahrenheit's thermometer, in the latitude of London, 51° 31′ 8″ N., must be 39.13929 inches: and as the further result of experimental inves-

By what proportion may we find the length of a second's pendulum, when we know the intensity of gravitation?

How may that length be ascertained by experiment?

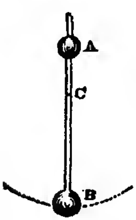
State some of the lengths actually found necessary in different parts of the earth, in order to produce the same number of beats per hour.

tigation, it may be added that at Melville Island, in the Polar Sea, Lat. 74° 47′ 12″ N., the length must be 39.207 inches; at the Galapagos Islands, Lat. 32′ N., 39.01719 inches; and at Rio Janeiro, Lat. 22° 55′ S., 39.01206 inches.*

120. As the force or intensity of gravitation decreases as the distance from the earth's centre increases, it follows that a pendulum, which would oscillate seconds at the bottom of a mountain one mile in perpendicular height, would not perform so many complete oscillations as there are seconds in an hour, if removed to the top of the mountain. Suppose the radius of the earth's circumference to be 4000 miles, as a second's pendulum would at that distance from the centre of attraction vibrate 3600 times in an hour, and therefore $86400 = 3600 \times 24$ in a day, it follows that it would lose the 4000th part of 86400 seconds in a day, at the distance of 4001 miles from the earth's centre. Now $86400 \div 4000 = 21.6$, that is, the loss would be 21.6 seconds in a day.

121. The length of a pendulum vibrating seconds being known, that of one which will vibrate half seconds, like those in most table clocks, or any other portion of time, may be readily calculated. For the times of vibration being as the square roots of the length of the pendulum, hence, as one second to 6.255, the square root of 39.125, so will half a second be to the square root of the pendulum required; that is as 1 : 6.255 : : 0.5 : 3.1275, the square of which will be 9.78. But the length of the half seconds, or any other pendulum, may be also found by taking the squares of the times, which will be directly as the lengths of the pendulums; thus as$(1 = 1^2)$sec. : 39.125 : :$(.25 = \frac{1}{2}^2)$sec. : 9.78, as before, or 9.7 inches, the length of a half second's pendulum.

122. A pendulum may be so constructed as to have its centre of oscillation far beyond the limits of its actual dimensions; and thus a pendulum only one foot in length, may be made to oscillate as slowly as another 12 feet long. Suppose a rod of iron, A B, to be loaded at both ends, and suspended at C, so that it might vibrate freely, it is manifest that though the arc described in each vibration would be limited by the length measured from the point of suspension, the velocity of the ball B, would be checked by the counterweight of the ball A, and the latter being moveable on the rod, the rate of vibration might be regulated at pleasure.



What would be the effect on the rate of a clock, of carrying it to the top of a high mountain? Why?

How may we calculate the true length of pendulums to vibrate in other times than *seconds*, when that of the latter is known?

How may the centre of oscillation be carried beyond the limits of a pendulum? Will this increase or diminish the number of its oscillations in a given time?

* See Abstracts of Papers printed in the Philosophical Transactions, from 1800 to 1830, vol. ii. p. 144, and p. 194.

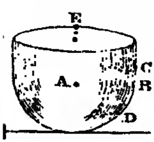
An instrument of this kind, called a Metronome, is used to mark, by its oscillations, the time in performing pieces of music.

123. A rod of uniform dimensions might be made to vibrate as a pendulum, without any ball or appendage whatever; but in that case the centre of oscillation would be raised, and such a pendulum must consequently be longer than one of the usual form. In a uniformly shaped rod or bar suspended at one extremity so that it might vibrate freely, the centre of oscillation would be at two-thirds of the distance between the point of suspension and the other extremity of the rod. Force applied at that part to arrest the motion of the rod would take complete effect, but at any other part a stroke would cause a tremour or irregular action of the moving body. Hence this point has been called the centre of percussion. In using a weapon of considerable length and nearly the same size throughout, as a cudgel or a sabre, the most effective stroke would be when the point of impact coincided with the centre of percussion; the situation of which must be at about two-thirds of the length of the weapon, its exact place depending chiefly on the relative weight of that extremity with which the blow is inflicted.

Centre of Gravity.

124. In every body or mass of matter at rest, there must be a certain point, in the direction of which, any force acting parallel to the surface on which the body is placed, will either be resisted by the weight and friction of the mass, so as to produce no effect, or if it be sufficiently powerful to overcome the resistance, the body will move in the direction of the force applied; but the same force acting against any part of the surface of the mass, not horizontally nor perpendicularly opposite to the point already mentioned, may cause the body to vibrate or be overturned, according to circumstances. This point is commonly called the centre of gravity, and sometimes the centre of inertia; and from the property just stated it might be termed the point of greatest resistance.

125. The annexed figure will serve to exemplify the phenomenon now described. Let A be the centre of gravity of a solid



body with a hemispherical base resting on a horizontal plane, then if pressure be applied vertically at E, it is manifest that it can produce no motion; but if applied at B, directly opposite to the centre of gravity, its effect will depend on the degree of force, as a small force will be destroyed by the inertia of the solid

What substitute might be employed as a pendulum instead of the rod and balls?

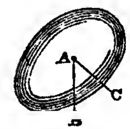
Where would the point of oscillation of such a pendulum be found?

When such a pendulum is to be suddenly arrested, where must the resistance be applied? Describe and illustrate the centre of percussion?

What is meant by the terms "centre of gravity," centre of inertia," and "point of greatest resistance," when applied to bodies? What states

mass, while a great force will be partly employed in counteracting the inertia, and partly in propelling the mass steadily along the level plane. Now if force be applied at C or D, or any other point above or below B, it will have some effect, however inconsiderable, causing the body to rock or vibrate, if the force be small, and to be overturned if the force be great.

126. The centre of gravity in all bodies is that point at which the influence of gravitation seems to be concentrated; and hence, in any body, unless that point be supported, motion will take place, and be continued till the body settles in a position in which the centre of gravity cannot sink lower. Therefore when no obstacle is opposed to the motion of a body, either by its peculiar figure or that of the surface beneath, it will always take such a position that a line drawn from the centre of gravity to the point where the body comes in contact with the surface below it will be the shortest that can be drawn from the centre to any part of its superfices. Thus an oviform body, placed as in the annexed figure, would not stand in the position represented, but would turn till the shorter line, A C, became perpendicular to the supporting surface, instead of the longer line A B.



127. If a body be supported from above, that is, if it be suspended from a fixed point, hanging freely, the centre of gravity will always settle in a vertical line beneath the point of suspension.

128. The exact situation of the centre of gravity must depend partly on the figure and partly on the uniform or varying density of the whole mass of any body. Suppose a body to be of uniform density throughout, its centre of gravity may be experimentally ascertained by balancing it on the edge of a square table, in two positions, when the lines of equilibrium will intersect each other at a point over the centre of gravity, which manifestly must be in the centre of the mass. A body of small dimensions may be more accurately balanced on the edge of a knife; or if the body can be conveniently suspended, and a plumb-line let fall from the point of suspension, its direction being traced from two such points, will be found to intersect each other as before, at a point on the superfices which will indicate the situation of the centre of gravity. If a body varied in its density in different parts, and possessed considerable thickness in proportion to its length and breadth, holes bored through the mass in directions vertical to different points of suspension, would meet at the centre of gravity of such a body.

of bodies result respectively from the support, and from the want of support to their centres of gravity?

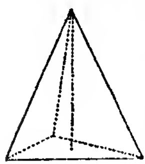
Of what comparative length will a line be found, between the centre of gravity of a body and the point of its superfices on which it rests?

What relative positions will be found between the centre of gravity of a body and its point of suspension?

On what two circumstances must the position of the centre of gravity depend? How can its situation be mechanically determined?

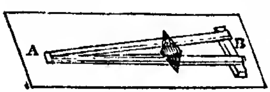
129. When the density of a body is uniform and its figure regular, the centre of gravity will be the central point of the mass; as in a globe, an elliptical or oviform spheroid, or a parallelopiped.

The surface of a triangle, its three sides, and its angular points, will all have the same centre of gravity, situated at two-thirds of the length of a right line passing from the vertex of the triangle to the middle of the base line. The centre of gravity of a cone will be at three-fourths of the length of its axis; and that of a hemispherical solid at five-eighths of the radius.



A pyramid and its four terminating points will have the same centre of gravity. The figure of a body may be such that the centre of gravity will not be included within the mass. Thus a hollow cone, as a common extinguisher, or any body of similar shape, would obviously have its centre of gravity in the void space within it; and so would a basin-shaped body or hollow hemisphere. A piece of wire twisted into the form of a horseshoe, or of a hoop, would also have its centre of gravity, not in the wire, but in the open space within it.

130. The manner in which the centre of gravity of a body, when unsupported, tends towards the lowest point it can reach, may be illustrated by an amusing experiment, made with a piece of wood or any suitable substance turned in the shape of a double cone united at the base, then if a jointed two-foot rule be opened a little way, and raised at the open end, so as to form a sort of



inclined plane, the piece of wood on being placed at the bottom of the plane, will roll along to the raised extremity of the rule, seeming to ascend the inclined plane, passing as in the annexed figure, from A to B. This is, however, merely an optical deception, for the centre of the double cone, which must be its centre of gravity, really sinks lower and lower between the sides of the rule as it advances to the open end.

131. A somewhat similar experiment with an inclined plane, serves to show the effect of the different distribution of density or weight, in different parts of the moving body. Suppose a cylinder

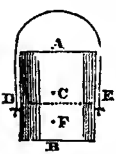
to be made of light wood or cork, and to have a plug of lead passed through it from end to end, so that its centre of gravity would be near its surface: if then it were placed on a moderately inclined plane with the loaded side towards the ascent, it would necessarily turn till that side rested on the plane; but it could plainly move no further, unless replaced, as in the marginal figure.

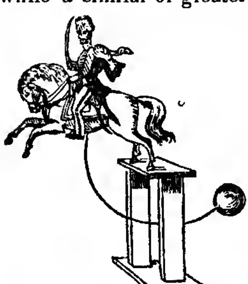
Where will it be found in bodies of uniform density and regular figure? How can you ascertain the centre of gravity in a triangle? a cone? a hemisphere? a pyramid? Does the centre of gravity necessarily fall within the mass of every figure?

What experiment illustrates the descent of the centre of gravity when unsupported? What one exhibits the influence of distribution of density?

132. The necessity of supporting the centre of gravity in every situation appears from the manner in which we move in the act of rising from a seat. When a person is sitting the centre of gravity of the body will be supported by the seat, from which it will be impossible to rise without bending the body forward so as to bring the centre of gravity over the feet, previously to assuming the erect position; or else lifting the body by resting the hands on the back or sides of the seat or some other point of support. The utter incapability of locomotion that takes place when an animal is so situated that it cannot by its own efforts raise the centre of gravity of its body, is strongly exemplified in the case of a fat sheep, or ewe with lamb, which has been so unlucky as to lie down on the border of a shallow ditch or trench in a field, and roll over on its back into the hollow, where, in spite of its utmost efforts, it would lie with its feet in the air till it perished with hunger, if not assisted to rise. A tortoise thrown on its back affords another striking example of the same kind; in this manner sea turtle are captured on shore.

133. From what has been stated it is evident that the stability of a body must be increased by lowering its centre of gravity. A cylindrical vessel A B, suspended by a handle turning on pivots fixed near the bottom, would inevitably overset when empty, as the centre of gravity C would then be above the points of suspension; but if a very heavy substance as quicksilver, or steel-filings, were poured into it, so as to fill it to the line D E, the centre of gravity would be reduced to F, and the vessel might be suspended with safety. Hence it may be perceived why vans and stage-coaches, if heavily loaded at the top, will be very liable to be overturned, while a similar or greater weight placed low down will prove a security from danger; and on this principle "safety coaches" have been constructed, with receptacles for heavy luggage under the bodies of the vehicles.

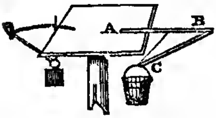




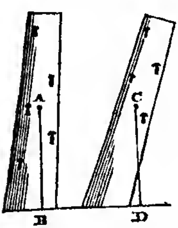
134. The effect of placing the centre of gravity of a body in a very low situation is shown in vibrating figures, such as that represented in the margin, and other toys for the amusement of children, formed on similar principles. Thus likewise a long stick or ruler, placed loosely on a bench or table, with more than half its length projecting beyond the edge of the board, may be made

How is the position of centre of gravity illustrated in the manner of rising from a seat? How is its importance shown in the positions of animals? What effect on the stability of a body has the depression of its centre of gravity? What familiar applications can be adduced?

to support a bucket of water or a half hundred weight suspended on it. The manner in which this is effected will be easily comprehended from the annexed figure, in which let A B represent the stick, which must have a notch or noose at the end B, against which rests another stick or prop, and the handle of the bucket being suspended by a string from the first stick, the prop pressing against the string at its junction with the handle C, fixes the bucket in such a position that the greater part of its weight and consequently the centre of gravity of the whole apparatus is supported by the table; and therefore, so long as the parts remain connected, the equilibrium will be preserved, for the end of the stick B cannot be depressed without raising the centre of gravity. A common tobacco-pipe, in the same manner, may be made to sustain any weight short of that which would completely crush it.



135. As a body of any kind cannot retain its position unless its centre of gravity be supported, it follows that stability may be preserved so long as a line directed from that centre vertically towards the surface below falls within the polygon formed by the base of the body in question. Hence the broader the base of any body the more securely will it stand; and on the contrary when the base is extremely narrow a body will easily be thrown down. If a portion of any mass overhangs its base, it may still remain standing so long as the vertical line from the centre of gravity falls within the base. Thus a column, an obelisk, or a steeple might incline somewhat from the perpendicular, and yet stand firm. From the inspection of the annexed figures it will appear that the inclination of a column might be greater than is represented in the first figure, where the line A B falls within the base, without endangering the stability of the body; but it must be less than that in the second figure, where the corresponding line C D falls without the base.



136. Most very lofty buildings swerve in some degree from the perpendicular after a time, yet there can be no hazard of their destruction if properly erected. The monument built by Sir Christopher Wren, near London Bridge, to commemorate the great fire in 1666, and the elevated spire of Salisbury Cathedral, have both become slightly inclined, but they will probably long remain to afford standing evidence of the consummate skill of their respective founders. Travellers have frequently no-

How do vibrating figures exemplify the position of centres of gravity?

What advantage does an extended base afford for preserving the stability of bodies? What examples prove that leaning bodies may sometimes have a stable position?

ticed the leaning towers of Bologna and Pisa, especially the latter which is ono hundred and thirty feet high, and inclines so much that the summit overhangs the base fifteen or sixteen feet; yet the line of direction from the centre of gravity dropping within the base, the structure has continued to stand or rather to lean for some centuries, and will probably endure centuries longer.

137. A change of tho position of a body which leaves its centre of gravity unsupported, must necessarily destroy its stability. Hence a high carriage is liable to be overset when one side is raised more than the other by the wheels passing over a bank or by the sloping direction of the road; and an over-freighted boat may be capsized somewhat in the same manner, by a sudden lurch throwing the weight on ono side. Such an accident may likewise happen in consequence of a person incautiously rising when a boat inclines to one side, the situation of the centre of gravity being thus altered, so as to swamp or upset the boat.

138. The impossibility of preserving any position without keeping the line of direction of the centre of gravity within what may be termed the area of stability, or polygonal surface by which the body is supported, may be experimentally illustrated by ohserving the effect of placing a person to stand with his heels close together and in contact with a perpendicular wall; for with such a position of the feet it would be found that he was unable to stoop sufficiently to touch the floor with one hand. The act of stooping is performed by bending the lower part of the body backward while the upper part is inclined forward, and thus though the situation of the centre of gravity is lowered, its line of direction still falls vertically between the feet. Now a person with his heels and of course his hack also against a perpendicular wall could not possibly bend backward, and in attempting to lean forward he would inevitably lose his balance and fall down. So that one might scatter a handful of silver or gold on the floor before a person stationed as just described, and offer him all that he could pick up, while he kept his feet unmoved, without the slightest risk of losing one's money. For the sake of any one who might choose to try the experiment it should be remarked that the terms specified must be strictly adhered to; for if the heels are raised so that the body is supported by the toes, it will no longer be impossible to stoop sufficiently to touch the floor without falling: the requisite condition therefore should be that the heels must remain in contact with both the wall and the floor.

139. A body will remain at rest, or in the state of equilibrium only in two cases, namely, when the centre of gravity is either as near as possible to the point of support, or as far from it as pos-

What facts prove the importance of preserving the line of direction of a body within its base? What is meant by *polygonal surface* or *area of stability?* What experiment shows the application of the principles of stability to the human body?

Under what two circumstances can the equilibrium of a body be preserved?

sible. In the former case, the stability of the body will be secure; in the latter, extremely insecure; thus a heavy elliptical solid laid lengthwise would require a considerable force to remove it from its place, but poised endwise the slightest impulse would cause it to roll over. When the centre of gravity is at the lowest point, a body is said to be in a state of stable equilibrium; and when it is at the highest point, in the state of instable equilibrium.

140. Many feats of dexterity, as walking on stilts, dancing on the tight rope, standing on a slack wire, and balancing bodies either in motion or at rest, depend chiefly on the power of maintaining the state of instable equilibrium. Walking on stilts, sometimes practised by school-boys, as an amusement, is adopted as a matter of convenience by the shepherds in a district called the Landes, in the south-western part of France. The country there being a sandy level sometimes covered with water, the shepherds on leaving home take their lofty stilts, and may be often seen striding along, on their artificial supports, at an immense rate. The art of rope-dancing is facilitated by holding in the hands a long pole in a transverse direction; for a trifling elevation of one end of the pole and consequent depression of the other may be made at any time, to prevent the lateral deviation of the centre of gravity from its proper position vertically above the rope. Standing or walking on the slack wire appears to be a more arduous feat than moving on the tight rope; yet it is practised merely by keeping the arms extended to preserve the equilibrium; and sometimes in that attitude the performer will make a further display of skill, by balancing bodies, one above another, on his chin. Occasionally an exhibition of dexterity on the slack wire is made to appear more difficult, by the performer having handed to him a chair, and a small table which he fixes across the wire, by resting on it the rails which connect the legs of the chair and of the table, then seating himself in the chair and placing his feet above the front rail of the table, he keeps the whole accurately equipoised even when the wire is made to swing from side to side. But though this feat has a more imposing effect than standing alone on the wire, there is no doubt that it may be performed with greater facility; for the table, and in a less degree the chair also serve, like the pole in the hands of the rope-dancer, to assist in maintaining the centre of gravity in its proper place.

141. These feats, curious as they are, appear much less wonderful than the exhibitions described by some ancient writers of respectability, in which elephants are represented as walking on a tight rope. The difficulty of preserving the centre of gravity of so unwieldly an animal, moving on such a narrow line seems

How do we distinguish the two states of stable and unstable equilibrium? What feats of dexterity refer to the conditions of equilibrium for their explanation?

What remarkable feats are related to have been executed on the same principle by quadrupeds?

nearly to approach impossibility; but the evidence of the fact appears to be deserving of credit.*

Mechanic Powers.

142. Nature presents to our notice force capable of producing motion, under various modifications. The weight of solid bodies, the impulse of flowing water, the pressure of currents of air, the muscular exertions of men or brute animals afford familiar examples of different kinds of forces or means of originating motion; and it is the peculiar province of mechanical science to supply rules for the accumulation, distribution, application, and expenditure of these or any other forces, in the most advantageous manner, by means of machinery.

143. In investigating the effect produced by any machine, there are three things to be considered: 1. The nature of the force applied, generally styled the power; 2. The force opposed to it, called the resistance; and 3. The point or points of connexion between the power and the resistance, which when there is only one point, as in the most simple machines, may be termed the centre of action, and where there are two or more such points, the action of the antagonist forces must be distributed over those points.

144. Weight being in itself one of the most efficient kinds of force, and at the same time a common property of all bodies to which force can be applied, it has been very properly adopted as a convenient measure or medium of comparison of moving forces in general. But as the mere weight of a body in motion can afford no just indication of its impulsive force, the term moment or momentum has been adopted to denote the absolute force of a moving body with reference to the effect it is capable of producing. The difference between the force of a body at rest and that of the same body in motion, that is between its weight and its momentum, in different circumstances, will be obvious on the slightest consideration. Thus a musket-ball which might not be heavy enough to break through a sheet of tissue-paper, when laid gently on it, would perforate a much firmer substance, if dropped on it from a considerable height, and fired from a gun it would penetrate a thick deal board. The momentum of a body then must be estimated by its weight and velocity taken together.

Enumerate some of the natural forces capable of producing motion.

What has mechanical science to do with these forces?

How many and what things require to be considered in examining the effect of a machine?

What is meant by the term *centre of action?*

What is the difference between force and momentum?

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* "Notissimus Eques Romanus elephanto supersedens per catadromum, id est funem, decurrit."—*Suetonius in Vita Neronis.* References to other writers, ancient and modern, who have noticed the exhibitions of elephants on the tight rope, are given in *Beckmann's Hist. of Invent. Eng. Tr.* vol. iii. p. 311.

145. From what has been stated elsowhere, it may be inferred that any force which would drive a body weighing two pounds a given distance in one minute, would drive a body weighing but one pound twice as far in the same time; and hence the velocity of the latter body would be double that of the former, though both impelled by the same force. Both bodies also would have the same momentum, as will appear on multiplying the velocity of each body respectively by its weight: for the velocity of the first-mentioned body may be represented by 1, and that of the last-mentioned, being double the other, by 2; then 2lb. × 1 = 2, and 1lb. × 2 = 2. And the same result will be obtained if we take the whole distance passed through hy each body in a given time as the measure of its velocity; for suppose the body weighing two pounds to run a quarter of a mile in a minute, and that weighing one pound half a mile in the same time; then ¼ m. = .25 × 2 =50, ½ m. = .50 × 1 = 50; the sum expressing the momentum of either hody being the same. Since the momentum of a moving hody is to be estimated by its weight multiplied into its velocity, it follows that a comparatively small body may by the celerity of its motion produce a much greater effect than a body of far superior bulk moving slowly. Suppose the weight of a battering ram (such as was anciently used in war), to be 20,000 pounds, and that it moved at the rate of one foot in a second; and the weight of a cannon-hall to be 32 pounds, and that it moved 1000 feet in a second, then the momentum of the former would be 20,000 × 1 = 20,000, and that of the latter 1000 × 32 = 32,000; and consequently the effective force of the cannon-ball would be more than half as great again as that of the ram, notwithstanding its immense superiority of weight.

146. The mechanic powers are simple machines, or instruments, by means of which the acting force technically styled the power, is to be applied to the force which must be overcome, or that called the resistance. The advantage which is obtained by using these mechanical agents arises from the distribution of the resisting force among the different parts of the machine, so that the portion of it which is directly sustained or counterbalanced by the power bears but a small proportion to the whole; and thus a power insufficient to communicate motion to a body or support its pressure, without mechanical assistance, may effect the purpose for which it is employed, by transferring a part of the weight to one or more of those points already noticed, whether it be the fulcrum of a lever, the wheels of a pulley, or the surface of an inclined plane.

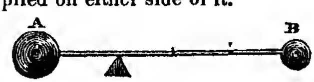
147. Different authors have varied considerably in the enumeration of the simple machines or mechanic powers, from the combination of which and their several modifications all other machines, including those of the most complicated nature, are pro-

Give some examples to illustrate this difference.
What is the nature and what are the objects of the *mechanic powers?*
Under how many general divisions may all mechanic powers be classed?

duced. Considered as modes of the application of impulse to overcome resistance, all the mechanic powers may perhaps be most correctly arranged under three divisions: 1. The Lever; 2. The Multiplied Cord; 3. The Inclined Plane. To these some have added the Wheel and Axle, the Pulley, the Wedge, and the Screw. But the wheel and axle is only a variety of the lever, the principle which regulates the action of both machines being precisely the same. The pulley, so far as it possesses any distinguishing property, must be considered as a multiplied cord; but in practice it is always used with wheels, and consequently it partakes in some degree of the nature of the lever. The wedge is nothing more than a double inclined plane applied in a peculiar manner, and acting exactly as a single inclined plane, but with twice the effect. The screw is a modification of the inclined plane, usually operating through the assistance of a lever. All these instruments have been commonly regarded as so many simple machines; it may therefore be as well to describe them separately, and in such order that the developement of their respective properties may illustrate the analogies among them which have been just pointed out.

The Lever.

148. The principle of action of all the mechanic powers is founded on the doctrine of equilibration, and is therefore intimately connected with the theory of the centre of gravity, which has been already explained. As no single mass of matter can remain in the state of equilibrium unless its centre of gravity be supported, so any number of bodies connected together must have some common centre of gravity on which they will rest securely, if undisturbed, or oscillate round that centre, when impulse is applied on either side of it.



149. Suppose two balls of iron, A, weighing three pounds, and B, weighing but one pound, to be fixed to the opposite ends of an iron bar; then whatever might be the length of that bar, (provided it was of equal diameter throughout,) the centre of gravity of the three connected bodies would be situated at a part of the bar just three times as far from the lighter ball as from the heavier, the weight of the latter being three times as great as that of the former; and the bar being supported at that point the equilibrium would be maintained. Such a bar would be a kind of lever, with respect to which the large ball might represent the resistance, or force to be overcome; the small ball the power applied; and the

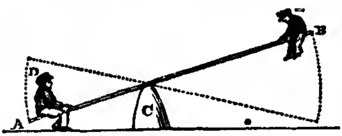
To which of these does the wheel and axle belong? to which the wedge and screw?

With what theory is the action of all mechanic powers connected?

What numerical relation exists between the length of the two arms of a lever and the forces applied at their extremities when in equilibrium?

supporting point the prop or centre of action, technically styled the fulcrum, which is a Latin word, signifying a prop.

150. The mode of action of the lever may be further illustrated by observing what takes place when two or more boys amuse themselves with a see-saw, or vertical swing.



Here the plank A B forms a lever, of which the block C is the fulcrum, and in order for the plank to be equipoised, it must be shifted into such a position that the greater weight of the boy D nearest the fulcrum, may be compensated by the greater distance from that fulcrum of the boy E.

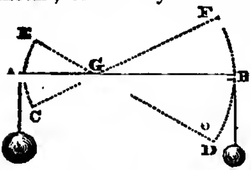
151. Any number of boys might be placed at either side of the fulcrum, provided that the sum of the weights of all the boys on one side, multiplied by their respective distances from the fulcrum, were equal to the sum of the weights of the boys on the other side, multiplied by their distances respectively from the same point. Thus, suppose the plank to be twelve feet long, and the fulcrum to be placed four feet from the end A, then a boy weighing thirty pounds at the end B would counterpoise another weighing sixty pounds at A; or the same boy at B would support two boys weighing forty pounds each, one being placed at A, and the other two feet nearer the fulcrum. This will appear from calculation, for the weight of the boy E, 30×8, his distance from the fulcrum, gives for the product 240; the weight of the boy D, 60×4, his distance from the fulcrum, also gives 240; and the weight of one boy at A, $40 \times 4 = 160$, and another at two feet from the fulcrum, $40 \times 2 = 80$, will by the addition of the products make 240. The plank being thus brought to a state of equilibration must, in order to make it vibrate, have some impulse given to it, either by the boys moving simultaneously upward on one side and downward on the other, and so on; or by pressing alternately with their feet against the surface below, as either end preponderates; or by any corresponding motion.

152. It has been proposed to adopt the principle of the see-saw in the construction of machinery for economical purposes. In the Journal des Savans, June 13, 1678, an engine is described, by means of which cripples, if even deprived of their limbs, being placed on the extremities of a long lever, might, by the alternate inclination of their bodies in opposite directions, produce sufficient effect to work the pistons of pumps for raising water. And in the same journal a description is given of a vibrating quadrangular frame, at one end of which four persons standing or sitting, might by their regulated efforts in depressing and raising the

From what species of amusement may a familiar illustration of this truth be derived?

In what manner has it been proposed to apply the principle of the see-saw to useful purposes?

frame, communicate a vertical motion to a saw for cutting timber; horizontal motion to surfaces for polishing marble, or levigating powders; force to a pair of shears for cutting through plates of metal; or rotatory motion to a wheel for any purpose. *



153. Since the momentum of a body is always to be estimated by its weight and velocity multiplied together, and the velocity by the space described by a moving body in a given time, it will follow that the momentnm of bodies in a state of equilibration must be the same. For let A B represent a lever kept in equilibrium by two leaden balls, the larger weighing two pounds, and the smaller one pound; then suppose the weights were removed, the lever would take the direction F D, the extremity A would describe the small arc A E, and the extremity B the arc B D, and those arcs would denote the spaces moved through by the respective ends of the lever. Hence tho momentum of the two weights necessary to preserve the equilibrium of the lever may be found by multiplying the absolute weight of each by the number representing the velocity, or space described; if therefore the arc B D be two inches, and A E one inch, it must be obvious that the products of the respective weights and velocities multiplied together will in each case be two, which would express the momentum or moving force exerted by each weight to preserve the equipoise of the lever. It must also be noticed that the arc B D, or F D, will always be in a direct proportion to the line G B, and the arc A C, or E C, will bear the same proportion to the line G A; so that, whether the number of pounds in each weight be multiplied by the number of inches in its corresponding arc, or by the number expressing its distance from the fulcrum, the result will show the momentum of both weights to be the same. For let G B be 12 inches, and G A 6, then $12 \times 1 = 6 \times 2 = 12$.

154. A lever theoretically considered must be an inflexible rod, of uniform weight in every part, turning freely on a fixed point or fulcrum. There are three kinds or orders of levers: 1. That in which the power P and the resistance R act in the same direction, having the fulcrum F between them; 2. That in which the power and resistance are in opposite directions, the latter being between

What is meant by momentum, when applied to bodies at rest? Exemplify this in the case of the lever.

What are the three characters of a lever assumed in theoretical investigations?

How many orders of levers may be enumerated? How are the several orders usually distinguished?

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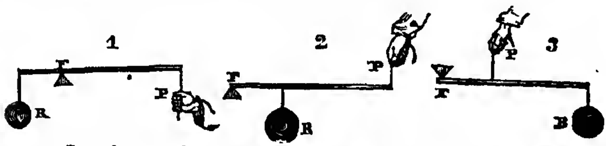
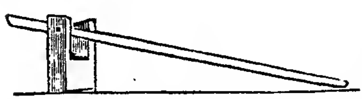
* This simple kind of machinery, known in French by the name of *bascule*, has been proposed for various other objects.—See *Borgnis Traite des Machines*.

the fulcrum and the power; 3. That in which the power and the resistance are also opposed, the former occupying the intermediate position, and being opposed to the fulcrum.



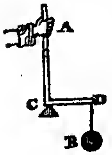
155. In a lever of the first kind, those parts on each side of the fulcrum are termed the *arms* of the lever; and the greater the relative length of that arm with which the power is connected compared with that to which the weight or resistance is attached, with so much stronger effect will the power be enabled to act. As the power will retain the lever in equilibrium when its momentum is barely equal to that of the resistance, it must have a greater momentum in order to produce motion. Now its momentum or acting force, so far as it depends on the lever, is derived from the superior length of the arm with which it is connected; and therefore in order to raise the weight or resistance, it must descend through a space as much greater than that through which the weight rises, as the length of the arm to which the power is applied is greater than the length of that arm to which the weight is appended. Thus by means of the lever, a small power can move a great weight; but in this case the space passed through by the power will always be greater than that through which the weight moves; and the greater the advantage which the power derives from the lever, the greater must be the difference of the lengths of its arms, and consequently the less will be the motion of the weight.



156. A long lever turning on a strong iron pin, as shown in the margin, is used by artillery-men to raise pieces of ordnance or other great weights. Wheelwrights and coachmakers employ a lever of similar construction, but having a shorter handle, and a higher fulcrum, and with this they raise a carriage on one side, when they want to remove a wheel. Crowbars and handspikes are levers of a similar kind, as also is the instrument called a jemmy, used by thieves, in breaking open doors or wrenching off locks or other fastenings. A pair of scissors, snuffers, or pincers, consists of two levers turning on a rivet, which serves as the ful-

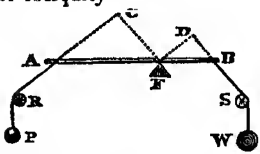
What are signified by the *arms* of a lever? From what is the mechanical efficiency of the *power* derived?
In what ordinary implements is the first order of levers exemplified? In what familiar example do the force and resistance act at right angles to each other?

crum, on one side of which power is applied to overcome resistance on the other side.

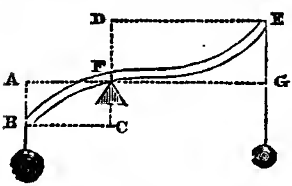


A common claw-hammer may be employed as a lever, acting with considerable effect in drawing out nails. In this case the line of direction of the power will be perpendicular to that of the resistance, as appears from the marginal figure.

157. Here the advantage obtained by the power is to be estimated by its vertical distance from the fulcrum A C, compared with the horizontal distance C D, between the fulcrum and the resistance, represented by the weight B. When the power, or resistance, or both act obliquely, their effect will be diminished, according to the degree of obliquity.



Suppose A B to represent a lever turning on a fulcrum at F, and let A R be the direction of the power P, and B S that of the weight W; then if the line R A be continued to C, and the line S B to D, and the perpendiculars F C and F D be drawn from the fulcrum to meet the lines of direction in the points C and D, the momentum of the power will be as its weight multiplied by the number denoting the length of C F, and the momentum of the resistance will be as its weight multiplied by the number denoting the length of D F.



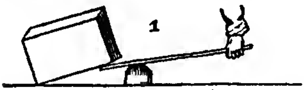
158. Let B E be a curved lever supported at F, and having the power suspended at E, and the weight at B; then the momentum of the former will be found by multiplying its weight by the line F G, or D E, and that of the latter by multiplying its weight by the line A F, or B C. These lines A F, and F G, are both shorter than the curve arms of the lever." If the fulcrum F be in a straight line between B and E, this lever will possess the same character as if the lever were straight; but if the fulcrum be situated out of a straight line while the force and resistance continue parallel, the lever will be progressive. This is the character of the bent steelyard, in which the poise being uniform, the weight is estimated by the height to which it will elevate the poise.

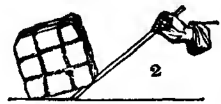
159. Whatever may be the nature of the lever employed, as whether it be of the first, second, or third kind, its mode of action is in every case to be explained according to the principles already

How is the advantage obtained by the *power* estimated when the directions of the force and resistance are not parallel?

Describe the bent lever. How may the mode of action of all levers be explained?

laid down. Thus in a lever of the second kind, in which the resistance, or weight to be overcome, is placed between the fulcrum and the power (see 154), the advantage of the latter will be increased in the same ratio, as that of the distance or space between the power and the fulcrum to the space between the resistance and the fulcrum.





160. The annexed figure (1) represents the manner of using a handspike or bar as a lever of the first kind: (2) shows how a similar bar may be employed as a lever of the second kind; the point of the lever here being fixed against the ground or surface below the body to be moved, and the power applied to the opposite end of the lever. Among the various examples which might be adduced of levers of the second order, may be mentioned the knife used by druggists for chipping sassafras, quassia, and other medicinal woods; one end being connected with a table by a hinge on which it moves as its fulcrum, the power is applied to the handle at the opposite extremity, and the substance to be chipped, forming the resistance, is placed between them, and is cut through by the edge of the knife pressing it against the table. The cutting blade used by chaff-cutters, and those of coopers, and last makers are likewise made to act on the principle of a lever of the second order.

161. In rowing a boat, regarding it as the weight or resistance to be moved, the water must be considered as the fulcrum, against which the pressure of the blade of the oar, acting as a lever of the second kind, moved by the hand of the waterman, as the power, at the opposite extremity, produces the motion of the boat. A pair of nut-crackers is formed by two levers of the kind just described, moving on a hinge as a fulcrum; and so likewise is a lemon-squeezer. When two men bear a weight on a hand-barrow, one of them may be considered as occupying the place of the power, and the other that of the fulcrum. If they have both the same degree of strength, and can support the barrow in a horizontal direction, the weight or burden should be exactly between them; for if it be placed nearer to one than to the other, an advantage will be given to the man stationed furthest from it.

162. In a lever of the third kind, (see 154) the power being nearer the fulcrum than the weight or resistance, the advantage lies on the

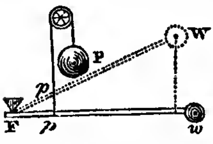
What implement illustrates the second order of levers?

In what manner may we explain the effect of oars in rowing?

How are we to compute the relative portions of a given weight borne by two persons on a pole?

How are the power, fulcrum, and weight arranged in a lever of the third order?

side of the latter; and therefore a greater degree of force would be requisite to support or move the weight by means of such a lever than that which would suffice to produce the same effect without the aid of any machine. But in this case the power will raise the weight through a greater space than that through which the power itself passes, and will consequently cause the weight to move with a velocity beyond its own.



This will appear from the inspection of the marginal figure, in which the power P, acting over a pulley, from the point of the lever p, will, in moving the lever to the position F p W, raise the weight or resistance from w to W, while the power only passes through the space from p to p; or more accurately the line described by the weight will be the arc w W, and that described by the point from which the power acts, will be the very small arc p p.

163. This kind of lever therefore is not used to overcome great resistance, but either to move a weight with great speed, or from its peculiar adaptation to some particular purposes. Thus, a builder in raising a long ladder from the horizontal position, to place it against a wall, finds it convenient to fix the foot of the ladder against a block or stone, as a fulcrum, and laying hold of the ladder at half or three-fourths of its length, he supports at first the greater part of its weight, but gradually bringing it nearer and nearer to a perpendicular position, he shifts his hands accordingly from the point where he first grasped it, till he can bring them low enough to keep the ladder upright, and then it may be removed to the required situation. The treadle of a turning lathe, or grinding machine, affords a familiar example of a lever of the third order, in which the pressure of the foot becomes the power, which, acting between the fulcrum and the resistance, sets the machine in motion. In a pair of tongs, or shears used in clipping the wool from sheep, two such levers are connected so as to have the fulcrum at the point of junction, and the hand in using one or the other, acts as the power between the fulcrum and the resistance.

164. But the most interesting examples of the application of such levers may be found in the structure of animals. Thus the fore-arm, connected with the upper part of the arm by the elbow-joint, moves on that joint as a fulcrum, the power that lifts or bends it being supplied by the contraction of muscles, acting from points between the elbow and the wrist. The whole arm is raised from the side of the body to a horizontal position in the same manner, chiefly by the action of a strong muscle called the Del-

What sort of mechanical advantage is it the purpose of levers of the third order to attain?

What practical applications of this order of levers can be named?

What parts in the structure of animals exemplify the third order of levers?

toid, forming the fleshy part of the shoulder, and stretching down on the outside of the arm, with the bone of which it is firmly connected. The bending of the knee-joint and the hip-joint in walking, is performed by the corresponding action of strong muscles; and in various parts of the human frame motion takes place in a similar manner. In the lower orders of animals an analogous kind of machinery may be discovered, as in the wings of birds, which are thus made to move with extraordinary velocity, that they may be enabled to act on a medium having so inconsiderable a degree of density as the air.

165. Any number of levers may be connected together, so as to constitute a composition or system of levers, the power acting on the end of the first lever raising the end of the second, and that depressing the end of the third, so as to raise a weight at the opposite extremity; or the alternate action may be continued through a great number of levers, the effect of which would be to augment vastly the momentum of the power, and to diminish in the same proportion the velocity of the weight, or resistance, so that the space through which that resistance would be moved would in general soon become very insignificant. The effect of such a system of levers must be estimated according to the relative distances of the power and the weight respectively from the fulcrum, whether the levers were all of one kind, or some of one kind and some of another.

166. Among the various applications of the lever, one of the most useful and important is in the construction of the common balance, styled, from its adventitious appendages, a pair of scales. The beam, which is the essential part of the machine, is nothing more than a lever of the first order, having equal arms, and turning freely on its fulcrum, or centre of action. It is hardly necessary to add, that its use is to ascertain the weight of bodies by equipoising them with an authorized standard; and the principle on which this is effected has been already amply illustrated. There are however some circumstances requisite to insure the accuracy of a balance, which deserve to be noticed.

167. The beam of the balance should be so formed that its centre of gravity may be placed just below the axis or centre of motion; for if the centre of gravity and centre of motion coincided, it must be obvious that the beam would rest in any position instead of assuming the horizontal direction necessary to indicate the equality of weights on each side. However, when a very delicate balance is required, its beam must be so constructed that the centre of motion may be as near as possible to the centre of gravity, but somewhat above it. The extremities of the arms of a balance are named the points of suspension, to which are fixed the scales; and those points should be so situated that a straight

In what manner may levers be combined together for the production of any desired effect?

How is the effect of such a system of levers to be estimated?

What circumstances are requisite to insure the accuracy of a balance?

line extending from one to the other would touch the point on which the beam turns. The sensibility of the balance is likewise influenced by the form of the fulcrum; and in the most accurate balances the beam rests on a knife-edge moving on agate, polished steel, or some very dense and smooth surface. Equal nicety is required in the suspension of the scales, which should hang from thin edges.

168. Having thus stated the method of rendering a balance as exact as possible, it may be proper to notice some of the imperfections of common balances, caused as they are too frequently by design, for the purpose of fraudulent deception. If the two arms be not precisely of the same length, the scale appended to the longer arm will turn with a less weight than that hanging from the shorter arm, and the purchaser of goods may thus be cheated: so also if one arm of the lever be heavier than the other, the scale on that side must preponderate. But deceptions of this kind may be discovered by changing the places of the weight and the article to be weighed; for the lightest scale would no longer keep equipoised. And yet with such a pair of scales the true weight of a substance might be ascertained; since by weighing it first in one scale and then in the other, multiplying together the two weights, and extracting the square root of the product, we should obtain the true weight.*

169. The steelyard is another well-known kind of balance, more directly involving the principle of the lever in its construction than the common balance. It consists of a lever with unequal arms, turning on its fulcrum, and having on the longer arm a moveable weight, so that the body, whose weight is required, being suspended from the shorter arm, the equilibrium is attained by shifting the weight to the necessary distance from the fulcrum, and the longer arm being graduated and numbered, the weight appears from inspection. This is sometimes called the Roman balance, as alleged from its resemblance to the Roman statera; though it has been stated that the original term was Romman, and that it was so called in the East, from the shape of the weight, resembling a pomegranate.† Such a balance as the steelyard, but of small dimensions, and made of ivory or wood, is used by the Chinese for weighing pearls, precious stones, and other small objects.

170. The Danish balance is a straight bar or lever, having a heavy weight fixed at one end, and a hook or scale at the other,

What are some of the defects liable to be found in balances?
How may a false balance be detected?
How may the true weight of an article be obtained by means of such a balance?
How is the action of the steelyard to be explained?
What is the construction of the Danish balance?

* See Leslie's Elements of Natural Philosophy, vol. i. p. 186.
† Idem, p. 187.

with a moveable fulcrum, the situation of which indicates the weight of any substance which may be tried by it. The bar of course is graduated, and thus the weight may be determined, but the divisions becoming smaller in proportion as the weight increases, inconvenience occurs in ascertaining the exact amount of the weight of very heavy bodies.

171. The weighing-machine used at toll-gates on turnpike-roads, to discover the weight of loaded carriages, consists of a system of levers supporting a quadrangular floor. Four levers turning on their fulcrums extend from the angles of a box beneath the floor towards its centre where they are connected together, and also with another lever extending across the middle of the box, and passing beyond its limits; this last lever acts on a third which presses on a spring or is connected with the arm of a balance, by means of which the amount of pressure on the whole system may be ascertained.

The Wheel and Axle.

172. Though the lever may be considered as the most generally applicable, and consequently the most useful of all simple machines, yet from the limited effect and intermitting action of power employed to overcome resistance by means of the lever, its grand utility must ever be confined to cases in which a momentary effort is required to change the place or position of a body of a great weight, by the application of comparatively small power. Thus, if it be necessary to remove a heavy block of marble or granite from one place to another, and a lever can be applied in such a manner to one side of its base as to shift the position of its centre of gravity sufficiently to make the block turn over, it may thus be rolled to any given distance: but supposing the utmost effect of the lever be to raise the mass but one inch, or any space through which it would fall back to its first position, the lever alone would manifestly be quite useless. Hence different methods have been contrived for rendering the lever more effective, as by employing a German machine, called a Hebstock, by which the weight is propped or supported during the intervals between the successive operations of the lever; by the French machine, termed Roue de la Garosse, from the name of the inventor, and by means of which a lever is kept in a raised position by a ratchet wheel; or by using the Universal Lever, which also acts by means of a ratchet wheel.*

To what objection is it liable?

What is the construction of weighing machines for carriages?

What circumstance limits the utility of the simple lever? How has it been proposed to obviate this defect?

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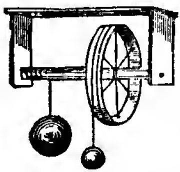
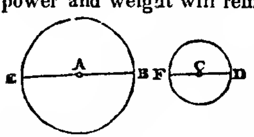
* This kind of wheel can only move forwards or in one direction, being prevented from turning the other way, by a spring detent falling between teeth on its periphery.

173. But those modes of operation must be nearly useless where it is requisite to raise a body to a great height, or move it through a considerable space, and for such purposes may be advantageously employed the wheel and axle, sometimes called Axis in Peritrochio,* which has generally been ranged among the the simple machines, or mechanic powers, though it is in fact only a more complicated form of the lever, and it might with propriety be styled a perpetual lever.

174. It consists of a wheel or large flat cylinder, with a smaller cylinder passing through its centre, as an axle, to which it may be fixed so as for both to move together about the same centre, or the wheel may turn on its axle, in which case the effect will be different from that where the parts of the machine are connected.



In investigating the operation of the wheel and axle both parts must be considered as turning on a common centre. Let the annexed figure represent a horizontal axle, resting at its extremities on pivots, or supported by gudgeons, so that it may revolve freely, carrying round with it the attached wheel. On the axis is coiled a rope which sustains the weight; and round the periphery of the wheel is coiled another rope, in a contrary direction, to which is suspended the power. Then supposing the machine to be put in motion, the velocity of the power will be to that of the weight, as the circumference of the wheel to that of the axle; for it will be perceived that the power must sink through a space equal to the circumference of the wheel, in order to raise the weight through a space equal to the circumference of the axle. And as the momentum of any body may be found by multiplying together its weight and its velocity, it follows that if the number of inches in the circuit of the wheel multiplied by the number of pounds in the power, produce a sum equal to the product of the measure of the axle multiplied by the number of pounds in the weight, then the power and weight will remain in equilibrium.



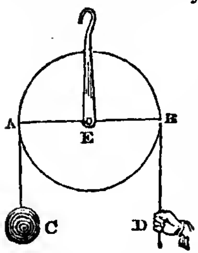
175. As before stated, the momentum of bodies moving in circles will be as the products of their weights and the radii of the circles they respectively describe, therefore when the power bears the same proportion to the weight as the radius CD or the diameter F D of the axle does to the radius A B or the diameter E B, of the wheel, the machine will preserve the equi-

What name might properly be applied to the wheel and axle? Of what does it consist? In what ratio are the power and weight to each other when this machine is at rest?

* From the Greek Αζων, an axis, and Περιτρεχω, to turn round.

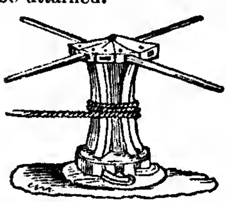
librium; so that the effect of this machine will depend on the superiority of the radius, or diameter of the wheel to that of the axle.

176. The wheel may be moved by a weight acting on its periphery, as already described; by projecting pins, or by a bent handle, such as is used for the common draw-well; but whether the power be applied directly to the circumference of the wheel, to the extremities of the projecting pins, or to the handle, its effect must be estimated by the extent of the circle described.



177. That the wheel and axle differs not in principle from the lever may be demonstrated from considering the effect of a single wheel used not for the purpose of increasing power, but merely in order that a power may be enabled to act in some required direction. For let C be any weight, as ten pounds, suspended over a wheel by a line held at D, it will be obvious that setting aside the effect of friction, a power equal to ten pounds must be applied to keep the weight equipoised. Now the pivot on which the wheel turns will manifestly be the centre of motion or fulcrum, supporting the joint action of the power and the weight; and the lines A E and B E will represent the equal arms of a lever held in equilibrium, like a balance loaded with equal weights.

178. A Venetian window-blind is usually suspended in this manner, by an endless line passing round two wheels; and while both sides of the line are equally stretched, the blind will remain at any height, but destroying the equilibrium, by pulling the line on one side or the other, will raise or lower the blind at pleasure. In the wheel and axle the radius of the wheel represents the longer arm of a lever, and the radius of the axle the shorter arm; and hence the advantage this machine affords. And as its action may be continued indefinitely, each revolution producing an uninterrupted effect, the power may be regularly applied till the object in view be attained.

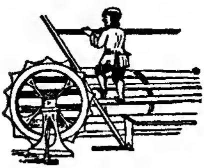


179. One of the most efficient forms of the wheel and axle is displayed in the capstan used on board ships and in dock-yards. It consists of a vertical spindle fixed firmly as in the deck of the vessel, but turning on its axis, and supporting a drum, or solid cylinder connected with it, and having its periphery pierced with holes directed towards its

On what will the effect of the wheel and axle depend? How is the effect of the wheel to be estimated, when the cord is not applied directly to its periphery? How can you prove the identity of the wheel and axle, and the simple lever? Of what practical applications is this machine susceptible? What is the construction of the capstan, and how is its effect to be computed?

centre. It is then worked by long levers, inserted in the holes by men who walk in succession round the capstan, and thus make it revolve, while a rope or cable wound about the spindle may act with force sufficient to weigh a ponderous anchor, or warp a heavy-laden vessel into harbour.

180. The treadwheel is anothor modification of the wheel and axle, in which the weight of several persons stepping constantly at the circumference of a long wheel make it revolve by their weight; as may be readily comprehended from the annexed figure. A somewhat similar wheel turned by the weight of one man is used in Persia and some other oriental countries, for raising water.

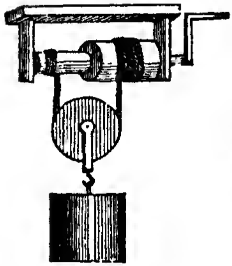


One or more horses may be made to work a mill, by harnessing them to the extremity of shafts or long levers fixed to an axis, which they turn round by walking in a circle; as in a machine for triturating clay for brick-making, and in some malt-mills. A treadwheel of a peculiar form is used in some parts of the United States acted on by horses, oxen, or other animals.

181. The axle of a wheel sometimes has a conical or tapered shape, which affords an advantage when a varying force is to be overcome. The mainspring of a watch, the power of which is employed to uncoil a chain, acts thus on an axis, called the fusee, on the surface of which is cut a spiral groove to receive the chain; and when the watch is newly wound up, the spring acts with its greatest intensity to turn the fusee while the chain passing round that part where the diameter is shortest, affords but a small leverage; and as the elastic force of the spring gradually diminishes by its relaxation, it obtains greater and greater purchase by the increasing diameter of the fusee as the chain is uncoiled; so that by this means an equability of action is maintained, without which the watch would be useless. A similar contrivance is adopted to equalize the effect of power applied in raising ore from a deep mine; for the rope, when at its greatest length, (and consequently when the resistance of the weight is greatest), is coiled about the narrow end of the axle, and the successive coils advance towards the wider extremity, as the resistance diminishes by the shortening of the rope.

182. As the efficiency of the wheel and axle, whatever may be its peculiar construction, is to be estimated by the ratio of the diameter of the wheel to that of the axle, it follows that increasing the former or diminishing the latter will augment the effect. Either method may be adopted to a certain extent; but if the wheel be extremely large it may be inconvenient and unmanageable; and on the other hand, if the axle be very slender, it will be weak and insecure. Both these evils are avoided in the construction

For what purpose is the treadwheel used in Persia?
What is the constructinn and advantage of the watch fusee?
How is the principle of the fusee applied in mining operations?



of the double capstan, an ingenious contrivance, said to have been brought from China. It consists of two cylinders differing in diameter, connected, as in the marginal figure, turning about the same axis, while the weight is suspended by the loop of a long cord, one end of which uncoils progressively from the smaller cylinder, as the other laps round the larger: thus the weight is elevated at each revolution through a space equal to half the difference between the circumferences of the two cylinders. So that the mechanical advantage of the machine, with its pulley, will be in the ratio of the diameter of the larger cylinder to half its excess above that of the smaller one; and therefore the equilibrium will be preserved, when the product of the power multiplied by the former is equal to that of the weight multiplied by the latter. This is true when the machine is moved by a hand rope applied to the larger cylinder; but when the crank is employed, twice *its* length must be substituted for the diameter of the larger cylinder.

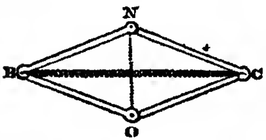
183. The efficiency of wheel-work may also be indefinitely augmented by a system or composition of wheels and axles, as in the case of the lever Thus the effect of the power that acts at the circumference of the first wheel may be transmitted to the circumference of its axle, with which a second wheel being connected may act through its axle on a third wheel, and so on to any given extent. One wheel may be made to turn another merely by the friction of their surfaces, when but little force is required; but the most direct and accurate method of connecting trains of wheel-work is by teeth or cogs, on the peripheries of the wheels; and on this principle a great variety of complex machines are constructed. Different wheels may also be connected by a strap or band, as is the case with spinning-wheels and the wheels of turning-lathes.

The Machine of Oblique Action, or Multiplied Cord.

184. To this kind of mechanic power may be referred all those cases in which force is transmitted by means of flexible cords or chains, from one point to another. It has also been styled the funicular system, but as including a variety of modes in which power can be applied by means of inflexible rods or bars, as well as by flexible lines, to produce an equilibrium depending on the

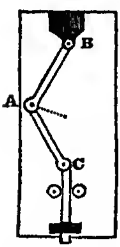
How is the double capstan, or *differential axle*, formed?
How much is a weight elevated by each turn of this machine?
How may the efficiency of wheel-work be augmented?
In how many methods may motion be transmitted from one wheel to another?

composition of forces, it might be, perhaps most properly, designated the machine of oblique action. From the theory of the composition of forces, which has been elsewhere illustrated, it may be assumed that a force applied in the proper direction will balance any two forces; but if one of these be sustained by some fixed point, the first force may be considered as acting only against the other; and power may thus be indefinitely augmented.



185. Suppose B N, N C, C O, and O B, to be four bars connected by joints or hinges at B, N and O, and by a spiral spring passing from the joint B, so as to unite it with the ends of the bars N C and O C at C. Pressure applied in the direction O N would elongate the spring with an effect which would increase in proportion to the decrease of the angle N C O, so that at the collapse of the bars B O and C O into a rectilineal position, the effect would be incalculably great.

186. If the end B of a pair of jointed rods bo firmly fixed, and the extremity C made to act by pressure, as by a man pushing at A, the force at C, when the bars are brought nearly into a straight line may be equal to the weight of many tons. On this principle that part of the Russel printing-press is contrived by means of which the paper is applied to the types to take off impressions; instead of using a screw turned by a lever, as in the common printing-press. The same kind of mechanic power is employed for extracting the steel core from the hollow brass cylinder used as a roller in the printing of cottons; and various modifications of it have been adopted, with great advantage in several operations of art, where a vast momentary effort is requisite to produce a given effect.



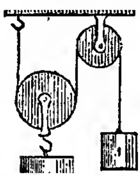
187. The theory of the machine of oblique action, as it applies to flexible cords, has been sufficiently explained in treating of the composition of forces. (See 35 & 36.) It may, however, be here stated, that if a cord be acted on by equal forces in opposite directions, its tension will be measured by one of those forces or weights, and must of course be uniform throughout; and whatever flexures the cord may undergo, and however numerous be the fixed points it passes over, provided its motion be unimpeded, the weights required to keep it in equilibrium must be equal. But if a cord be fastened at one extremity and variously deflected, the effect of weights suspended to different parts of it will be modi-

On what theoretical principle is the machine of oblique action founded? Illustrate its application in the hinged apparatus or *toggle-joint.*
How is this machine applied in the printing press?
For what species of effort is it peculiarly adapted?
What measures the tension of a cord stretched by equal weights at the extremities?

fied according to their situation; so that a great weight acting near the point of suspension may be counterbalanced by a comparatively small force at the opposite extremity of the cord.

The Pulley.

188. This is rather a compound than a simple machine; for from the investigation of its nature and properties it will be evident that it is merely a combination of the wheel and axle with the multiplied cord; and as the wheel, though a very useful, is not an essential part of the pulley, this machine may be regarded as a variety of the funicular system, or multiplied cord.



189. The effect of a single pulley, or moveable wheel suspended by a cord from a hook at a fixed point, as in the annexed figure, will be to diminish the resistance by one-half, so that a power equal to one pound will support a weight of two pounds. This must be manifest from considering that half the weight is supported by the hook, consequently the other half only is opposed to the power. The same conclusion will be derived from attending to the result of the action of the power in raising the weight; for double the length of rope must pass over the fixed pulley on the side of the power compared with that which passes over it from the weight; so that the power must descend two inches in order to raise the weight one inch. Thus the power will move as fast again as the weight, therefore its velocity must be double that of the weight, and its effect must be increased by such a pulley in the same ratio.

190. The fixed wheel or pulley here, has no other effect than that of altering the direction of the power. (See 177.) Though a pulley might obviously be made to act without wheels, and the cord might be deflected by passing through rings or by other means, so that the wheel must be considered as a sort of adventitious appendage to the pulley, yet, as already observed, it is an extremely useful one. For the wheel enables the cord to move freely, by destroying in a great measure the friction which would otherwise take place between the cord and the surface over which it passes, and which would weaken, and in some cases interrupt, the action of the pulley. The wheels also serve the important purpose of keeping the deflected parts of the cord stretched in parallel lines; for the effect of the power would be diminished in

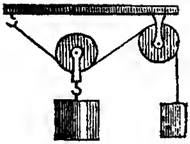
When one extremity of a cord is fastened to an immoveable point, how will weights applied to intermediate points affect the cord?

How may the pulley be regarded in a theoretical view?

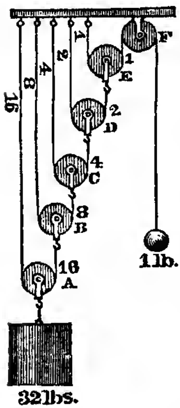
How are we to compute the effect of a single moveable pulley?

What is the effect of a single fixed pulley?

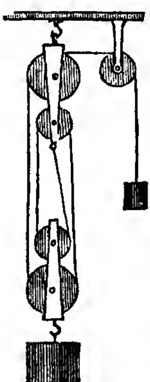
What is the advantage of the wheel in the construction of this machine?



any other position of the cord. Thus when the deflections of the cord form an angle, as represented in the margin, the power must be equal to more than half the weight, in order to keep the latter suspended; the machine will become less and less efficacious as the angle formed by the sides of the cord increases; and when the two parts of the cord supporting the weight approach nearly to a straight line, the power must be greater than the weight to enable it to preserve the equilibrium.

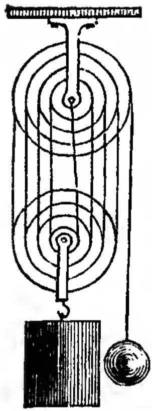


191. In the pulleys just described, is exhibited the effect of the power when the weight is partly supported from one fixed point; but that effect may be vastly augmented by such a system of pulleys as that in the annexed figure, in which the weight is suspended from the lowest of a series of wheels, each having its own cord attached to a fixed point. Here the resistance is diminished by the distribution of the weight over five fixed points; so that supposing the weight to be thirty-two pounds, the wheel A, with its cord, will support the whole of that weight; the wheel B, with its cord, half the weight or sixteen pounds; C, one-fourth of the weight or eight pounds; D, one-eighth or four pounds; E, one-sixteenth or two pounds, which being divided by the two sides of its cord, leaves but one pound to be supported by that side which is extended over the fixed pulley F; and thus a power equal to one pound will counterbalance a weight of thirty-two pounds.



192. When one cord only is used, which passes over two or more fixed and moveable pulleys, the power will be to the weight, as unity, or the single part of the cord supporting the power, to the number of the deflections made by the cord in passing over all the fixed and moveable pulleys. Hence if the power be augmented, so as to raise the weight, the former must descend through as many inches more than the latter ascends, as the number of bends in the cord supporting the lower block exceeds unity: that is, the power must sink four inches or feet to elevate the weight one inch or foot; and such will be the ratio of its efficiency with such pulleys as that shown in the marginal figure, the advantage gained depending on the number of wheels and consequent deflections of the cord.

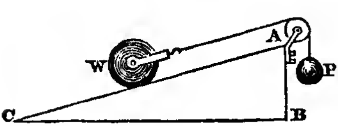
How does the obliquity of the cords affect the relation between the



193. A great variety of systems, or, as they are commonly termed tackles of pulleys, have been contrived; but the advantages they respectively afford may always be estimated by reference to the spaces relatively described by the power and the weight or resistance. The greatest inconvenience occurring in the practical application of the pulley, is owing to friction, and consequent irregularity of action. Various plans have been adopted to remedy this defect; one of the most ingenious of which consists in cutting a proper number of concentric grooves on the face of a solid wheel, with diameters, as the odd numbers, 1, 3, 5, &c., for the lower block, and corresponding grooves on another such wheel, with diameters, as the even numbers, 2, 4, 6, &c., for the upper block. Then the cord being passed in succession over the grooves, as represented in the margin, it will be thrown off by the action of the power, in the same manner as if every groove formed a separate and independently revolving wheel. A machine of this construction is called White's pulley, from the name of the inventor, Mr. James White, who obtained a patent for it.

194. Tackles of pulleys are used on board ships, where the wheels are fixed in blocks, by means of which the sailors can raise the masts, hoist the sails, and conveniently perform other necessary operations. Various combinations of pulleys are likewise used on land, as by builders, in raising or lowering great weights; and in removing from one level to another heavy bales of goods, or other merchandize.

The Inclined Plane.



195. This is the least complicated of all the simple machines. It is, as the name implies, a plane surface, supposed to be perfectly smooth and unyielding, inclined ob-

power and the weight? How many times is the power multiplied by means of the system of attached cords and moveable pullies combined? In what manner is the weight distributed among the cords in this arrangement? How is the relation between the power and weight to be discovered when a single cord is combined with a system composed of fixed and moveable pullies?

In what general manner may the advantage of a tackle be computed? What practical difficulty is encountered in the use of pullies with separate wheels? How does White's pulley obviate this difficulty? State some of the useful applications of the pulley.

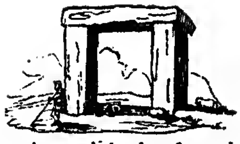
What theoretical character is assumed in treating of the inclined plane?

liquely to a horizontal plane; and its effect, as commonly used, is to diminish resistance, and thus enable a moderate power to sustain or overbalance a great weight. The mode of action of the inclined plane has been already fully explained (see 93 to 96), and the method of estimating its efficiency, in any given case, may be readily comprehended by reference to the relative velocities of two bodies, one falling through a space equal to the vertical height of the inclined plane, and the other passing down its declivity. Suppose the height A B to be one foot, and the inclined surface A C to be four feet, then a weight of four pounds, W, resting on the plane, will be equipoised by a weight of one pound, P, hanging freely over a pulley. And as the inclined plane is commonly employed to facilitate the rolling or shifting of ponderous bodies from a lower to a higher level through a moderate space, its efficiency will he in the ratio of the length of the inclined plane to its vertical height; thus with the machine just described, one-fourth of the force necessary to lift a great weight through the space A B, or the vertical height, would be sufficient to impel it up the declivity, from C to A.

196. In this more than in most other machines great allowance must he made for the effect of friction, which must materially modify any calculation as to the advantage it affords. Instances of the application of the inclined plane to practical purposes so frequently occur, that it can scarcely be necessary to advert to them. Roads formed on declivities are a kind of inclined planes; and railways are sometimes thus constructed, in such a manner that any weight, as a loaded sledge, may be made to ascend one plane or inclined railroad by the impulse of another carriage with which it is connected, and which passes simultaneously down an adjoining railroad.

197. The very simple nature of the inclined plane renders it probable that it was the earliest of the mechanic powers known and brought into use. It has heen conjectured that it was employed by the Egyptians in raising the immense blocks of stone which form the pyramids, and in executing other gigantic works, which have excited the astonishment of successive ages. Mr. Warltire, a gentleman who delivered lectures on natural philosophy, in the latter part of the last century, endeavoured to prove that the ancient British Druids were the founders of Stonehenge, on Salisbury Plain; and that they erected the massive trilithons, which partly compose that curious structure, by rolling or rather by shifting the transverse blocks into their places by means of temporary incl'ned planes of earth or rubbish, forming a sort of road-ways for the passage of the several block. The annexed figure

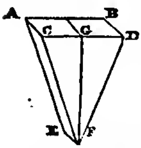
How is its mechanical efficiency estimated?
What familiar applications of the inclined plane may be enumerated?
What conjectures have been formed respecting its use among the ancients?



will afford a sufficiently accurate idea of one of the trilithons of Stonehenge, and when the structure was perfect, several of these were arranged in a circular figure. It will not be difficult to conceive that a sloping bank or declivity, having but a small degree of inclination, might be formed, up which any mass might be impelled or dragged, with a force not much greater than would be required to draw or push it forward on level ground.*

The Wedge.

198. A wedge is the solid figure called by Geometricians a triangular prism, bounded on two sides by equal and similar triangles, and on the other three sides by rectangular parallelograms. It is composed of two inclined planes united at their bases; as will appear from the annexed representation.



Its use is to divide solid bodies, the edge E F being impelled against them by pressure or some other force applied at the surface A B C D; and if the force be estimated by its weight, its effect will be in the ratio of the line D F to the line G D, that is as the sides of the wedge to its breadth. So that the advantage derived from using this machine increases in proportion as the angle which forms its edge diminishes. But the wedge is generally used for cleaving blocks of wood or other hard substances, and the force applied to it is that of percussion, with a heavy hammer or mallet, the effects of which are so different from those of direct pressure, and are so much modified by circumstances, as to render any theoretical calculation utterly inaccurate and useless.

199. It appears from the results of some experiments made in the Dock-yard at Portsmouth, England, on the comparative effect of driving and pressing in large iron and copper bolts, that a man of medium strength striking with a mall weighing eighteen pounds, and having a handle forty-four inches in length, could start or drive a bolt about one-eighth of an inch at each blow; and that it required the direct pressure of 107 tons to press the same bolt through that space, but it was found that a small additional weight would press the bolt completely home.*

200. But numerous and varied experiments would be requisite to obtain any results which might afford data for computing

What is the geometrical form of the wedge? What relation has the advantage of this machine to the angle formed at its edge? Of what nature are the forces usually applied to the wedge?

What has experiment proved in regard to the difference between pressure and percussion?

* Encyclop. Metropol.– Mixed Sciences, vol. i. p. 52.

the effect of impact or percussion on wedge-shaped bodies; and if that effect could be exactly estimated, further difficulties would arise from considering the very heterogeneous nature of the resistance, depending on the relative hardness, tenacity, and other properties of those substances on which the wedge is made to act. This instrument must therefore be regarded as one the effect of which can seldom be precisely determined; but which notwithstanding may be often very advantageously employed in certain circumstances.

201. Among the less frequent modes of application of the wedge may be mentioned its having been used to restore to the perpendicular position a building which declined slightly in consequence of some defect in the foundation. The voussoirs of arches are so many wedges; and piles used for the foundation of the piers of bridges may be considered as wedges, driven into the bed of a river by the percussion of a powerful machine. Sharp-edged and pointed instruments in general act as wedges; thus chisels, planes, and axes used by carpenters manifestly produce the effect of wedges; and knives, razors, awls, pins, and needles, and indeed all cutting and piercing instruments display an obvious analogy to the common forms of this mechanic power.

The Screw.

202. The screw, though commonly reckoned among the mechanic powers or simple machines, cannot be considered as such when applied to any practical purpose, as it would be found almost wholly ineffective without the assistance of the lever, which is therefore usually combined with it, and thus it becomes a most powerful machine, applicable to a variety of important purposes. The general form of the screw must be too well known to require description: it may however be stated, that it consists of two parts, namely a solid cylinder, sometimes called the male screw, and a corresponding cylindrical cavity, to receive the former part, and therefore styled a female screw; round the surface of the cylinder passes what is termed the thread of the screw, describing from one end to the other a curve sometimes inaccurately represented as a spiral, but which is really a helix, precisely resembling a common corkscrew, which, in fact, is nothing more than the helical thread of a screw without the core. The hollow screw has a similar helical thread winding within it, exactly adapted to the interval between the turns of the thread of the solid screw;

Why is the actual effect of the wedge more difficult to be computed than that of other machines?

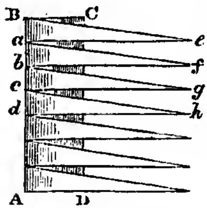
Of what applications is the wedge susceptible in the art of architecture?

Name some of the familiar applications of the wedge in ordinary instruments.

What is the nature of the screw in its practical structure?

and thus either part being made to revolve while the other is kept steady, motion or pressure may be produced to any extent.*

203. In order to obtain a correct estimate of the mechanical effect of the screw, it will be necessary to develope its construction, from which it will appear that it is, in principle, identical with the inclined plane; and it might be conceived to act as a system of revolving inclined planes. This will appear from reference to the annexed figure. Let A B C D represent a cylinder divided longitudinally into a number of equal parts, B *a*, *a b*, &c., and let lines *a e*, *b f*, &c., be drawn perpendicular to the side A B, each equal to the circumference of the base; then by joining B *e*, *a f*, *b g*, *c h*, will be formed so many right-angled triangles B *a e*, *a b f*, *b c g*, *c d h*, as the number of equal parts into which the cylinder has been divided. Now suppose these triangles to be rolled upon the cylinder, so that the point *e* should coincide with the point *a*, *f* with *b*, *g* with *c*, *h* with *d*, and so on, the hypothenuses or longest lines of the triangles, B *e*, *a f*, *b g*, *c h*, &c. would form on the surface of the cylinder one continued helical line, representing the thread of a screw. These triangles might be considered as a series of inclined planes; and therefore if such a screw were fitted to a hollow or female screw, fixed so that the former might act vertically, it will be obvious that one revolution of the male screw would raise or depress it through a space equal to the height of one of the inclined planes, and the effect of the screw, independent of friction, would be as the length of its base to its height, or as the line *a e* to B *a*. If then B *a* be $\frac{1}{8}$ of an inch, and *a e* $1\frac{1}{2}$in. or 12-8, a power equal to one pound acting by means of the screw would balance a resistance equal to twelve pounds. The power must here be supposed to act parallel to the base.



What is the distinction between a helix and a spiral?
How is an accurate estimate of the effect of the screw to be obtained?
With what other simple machine is its principle of action to be compared? How much does one turn of the screw raise the weight or remove the resistance?

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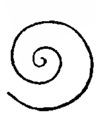
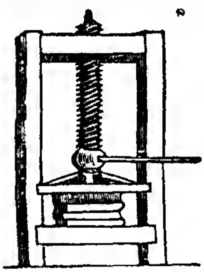
* A spiral or volute is a line which can be described on a plane; but no two points of a helix are in the same plane, and therefore it cannot be correctly described on a plane surface.

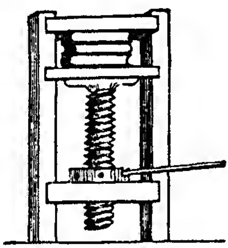
Spiral Line.



Helical Line.

204. But the resistance arising from friction between the parts of the solid and the hollow screw would in most cases require great additional power to produce any considerable effect. This therefore renders the application of a lever necessary to constitute the screw an effective machine. The lever may be added to the solid screw, to turn it within a fixed hollow screw; or to the hollow screw, to turn it round the solid screw. The manner in which the lever is applied in either case will appear from the following figures; the former of which shows how pressure may





be produced by a solid screw acting within a hollow screw in a fixed beam; and the latter exhibits the similar effect of a hollow screw pierced in a block turning by means of a lever on a fixed screw; the pierced block thus adapted to a solid screw is called a nut.

205. As the effect of the screw is always to be estimated by the proportion between the space described by the power, in one revolution of the screw, and the space between any two of its contiguous threads, it must follow that when the power is applied to a long lever instead of being made to act directly on the circumference of the screw, the effect must be vastly augmented. Thus if the threads of a screw be as much as half an inch apart, and it be turned by means of a lever extending three feet from the centre of the screw, the effect or advantage of such a machine will be as the number of half inches in the space described by the extremity of the lever to unity. Now reckoning the circumference of a circle in round numbers to be three times its diameter, the circumference described with a radius of three feet will be $36 \times 2 = 72 \times 3 = 216$ inches, and double that number, or 432 to 1 will be the measure of the advantage afforded by the machine.

206. Hence it will be apparent that the efficiency of the screw acted on by the lever might be indefinitely increased by extending

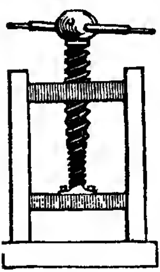
Why is the addition of a lever necessary in this machine? In what two modes may the lever be applied?

How is the effect of the screw to be estimated?

How far might the efficiency of the screw, theoretically considered, be increased?

the length of the lever, or by diminishing the interval between the threads of the screw. But a very long lever would be awkward and inconvenient, and extremely thin threads would be broken by the pressure when any considerable force was applied to turn the screw; so that either method of improving its action could be practically serviceable only to a limited extent. There is, however, a kind of double or compound screw, invented by John Hunter, the celebrated surgeon, bearing much analogy to the double capstan or axle, already described, (see 182) by means of which the mechanical efficacy of the machine may be augmented to any extent without at all diminishing its strength or compactness.

207. The marginal figure, which will show how this object is attained, represents a larger screw turning in a hollow screw or nut in the fixed beam, and having within it a concave screw adapted to the lower or smaller screw, and so arranged that while the larger screw passes forward the smaller one will be retracted; hence as both screws must revolve together, in each revolution, the moveable beam will be pressed downward through a space equal to the difference of the distances between the threads of the larger and the smaller screws. Therefore such a machine, in which the threads of the upper screw were 1-20 of an inch apart, and those of the lower screw 1-21 of an inch, would have the same effect as a simple screw, the threads of which were only 1-420 of an inch apart; for 1-20 — 1-21 = 1-420, the difference between the distances of the threads of the double screw just described.



208. A solid screw revolving on fixed axes, and having its thread adapted to teeth on the periphery of a wheel, is called an endless screw; forming a part of a compound machine of considerable power and utility. Fly-wheels, as that of a common jack for roasting meat, are sometimes turned by the action of a toothed wheel on an endless screw.

209. Besides its usual application to the purpose of producing a high degree of compression, as in the cider-mill, the common printing-press, and a variety of similarly acting machines, the screw is likewise employed to measure extremely minute intervals of space. The manner in which this object is attained will be best understood by referring to the theory of the screw, (see 205) where it is demonstrated that any circle described by an arm or index

By what two expedients might this increase be effected?
What practical difficulties prevent the unlimited augmentation of the power of the screw?
What is the construction of Hunter's differential screw?
Through what extent does a single turn of this screw move the platen of the press?
In what manner is the endless or tangential screw applied for mechanical purposes?

revolving parallel to the circumference of the screw will have a certain relation to the space between any two contiguous threads; and therefore a small arc of such a circle may be conceived to measure the indefinitely minute space through which the point of the screw would advance or retreat in any given portion of one complete revolution of the screw. Suppose the threads to be ¼ of an inch apart, and a circle fixed to the head of the screw to be divided on its border into 100 equal parts, then on turning the screw, the index would show the motion of the point of the screw through as small a space as 1-400 part of an inch. The interval between the threads of a screw for such a purpose might be extremely minute, or Hunter's screw might be adopted; and the circle of equal parts might be of sufficient extent to be divided into 360 degrees, or any larger number of parts; and thus the means would be afforded for measuring with perfect accuracy the almost invisible fibre of a spider's web, or for taking the dimensions of the capillary vessels through which circulate the juices of plants and animals, or for discovering the size of microscopic insects or other objects too minute to be perceived by the naked eye. An instrument adapted to a microscope for such purposes is called a micrometer,* and its screw a micrometer screw.

Compound Machinery.

210. The advantage derived from combining together two of the mechanic powers, as the lever with the wheel and axle, or with the screw, has been already detailed; and it is by means of combinations of the simple machines, under their various modifications, that a vast multitude of complex machines are produced, which are adapted to facilitate the numerous operations required in the several departments of the arts, manufactures, and domestic economy.

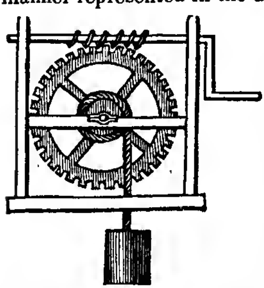
211. Among all the simple machines there is no one so generally useful, and therefore so frequently making a part of compound machinery as that modification of the lever called the wheel and axle. Its advantageous adaptation to the purposes of the mechanist is partly owing to the nature of the motion to which it gives rise, namely rotation, which is capable of being uninterruptedly continued through a period of indefinite extent; and to this advantage may be added the extreme facility with which wheels may be connected in various modes with other kinds of machinery. Hence there are few complex machines of which

What is the construction and use of the micrometer screw?
On what are the divisions of a thread measured in a screw of this description?
In what manner are the simple machines commonly adapted to the mechanic arts?
By what peculiarity is the wheel and axle rendered more serviceable to the mechanist than the other simple machines?

* From the Greek Μικρος, little; and Μετρον, a measure.

wheels do not constitute the most effective or essential parts. Thus are formed a vast variety of mills, from the coffee-mill to the powerful and complicated engine called a rolling-mill, for compressing plates of iron and cutting them into rods or bars; all the multifarious kinds of wheel-carriages; turning-lathes, and grinding-machines; clocks, watches, and timekeepers, in general; spinning-jennies, and many other machines used in the cotton, linen, woollen, and silk manufactures; and steam-engines under many of their modifications, to accommodate them to the purposes to which they are devoted.

212. The peculiar methods in which the parts of machinery are connected, or the modes of action of one mechanic power upon another, or upon a different form of the same power, are variously diversified to suit particular purposes. The wheel and pinion, represented in the margin, consists properly of two wheels of unequal dimensions, the larger having teeth on its circumference which are adapted to correspondent teeth, or as they are sometimes called leaves, in the smaller wheel or pinion: thus a pinion may be made to act on a crown wheel, that is a wheel with teeth placed at right angles to its circumference; as may be observed in a watch, or timekeeper. The endless screw is connected with the teeth of a wheel in the manner represented in the annexed figure.



213. A little attention to the mode of action of many machines in constant use will afford opportunities for observing numerous instances of the different ways in which trains of wheel-work are combined together, or made to aid the effect of the other mechanic powers. These are, however, generally reducible to two methods of proceeding, namely, either by teeth, cogs, or some similar parts, acting against each other, as just described; or by bands, as cords, chains, or other flexible lines passing wholly or in part round one or more wheels and axles, so as to produce simultaneous motion.

214. With respect to the use of either of these methods, it is of importance to observe the peculiar nature of rotatory motion, which differs most essentially from what is termed a motion of translation, or passage from one place to another, though it may or may not accompany such a motion. Suppose any body, as a billiard-ball,

Enumerate some of the applications of wheel-work. Describe the wheel and pinion.

By what two methods is motion communicated from one part to another in a system of wheel-work?

How does a motion of simple rotation differ from one of translation?